Accelerating Carbon Capture and Storage Implementation in Alberta

Alberta Carbon Capture and Storage Development Council

Final Report

March 2009

ALBERTA CARBON CAPTURE AND STORAGE DEVELOPMENT COUNCIL

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March 4, 2009

Honourable Mel R. Knight
Minister of Energy
Government of Alberta
404 Legislature Building
Edmonton, AB
T5K 2B7

Dear Minister Knight:

The Alberta Carbon Capture and Storage Development Council is pleased to present *Accelerating Carbon Capture and Storage Implementation in Alberta*, a blueprint to achieving swift, safe and widespread adoption of carbon capture and storage (CCS) in Alberta.

With the 2008 announcement of a $2-billion CCS program, Alberta has once again tapped its pioneering roots and has assumed a globally leading role in the development of CCS technology. The projects that will result from this program will create important momentum. Now is the time to prepare to capitalize on that momentum. Our report confirms the potential of CCS to make a meaningful impact on greenhouse gas (GHG) emissions, and it sets forth the path we believe we must follow to make this potential a reality.

Developing and implementing CCS technology is a tremendous opportunity for Alberta and for Albertans. CCS funding is an investment in the environment because it will significantly reduce GHG emissions. CCS funding, by both government and industry, is equally an investment in the economy because it ensures that GHG-emitting industries remain competitive on the international stage and it spurs a wealth of growth opportunities that Albertans are uniquely positioned to capitalize upon. Ultimately, CCS will be one of the keys to sustaining and building upon the standard of living that Albertans have earned over the generations through their ingenuity and hard work.

We are on the cusp of a new era with this emerging technology. We need to forge ahead in unison to ensure success. I hope we can count on The Government of Alberta's continued commitment to the deployment of CCS.

I would like to personally thank each member of the Council and those who participated on the sub-committees. I think I can speak for all of us in conveying that it has been an honour and a pleasure to serve Albertans with our efforts. We trust that *Accelerating Carbon Capture and Storage Implementation in Alberta* will meet with your satisfaction. We would certainly welcome your feedback, as well as periodic updates on the Government of Alberta's progress on the CCS file.

Yours truly,

Jim Carter, P.Eng.
Chair
Alberta Carbon Capture and Storage Development Council

Alberta CCS Development Council Final Report

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Acronyms and Units

AERI	Alberta Energy Research Institute
AOSTRA	Alberta Oil Sands Technology and Research Authority
ASAP	Alberta Saline Aquifer Project
CAPP	Canadian Association of Petroleum Producers
CEPA	Canadian Energy Pipeline Association
CERI	Canadian Energy Research Institute
CSA	Canadian Standards Association
CCS	carbon capture and storage
CO_2	carbon dioxide
EE	energy efficiency
ERCB	Energy Resources and Conservation Board
EOR	enhanced oil recovery
EU	European Union
Gt	gigatonne (billion metric tonnes)
GHG	greenhouse gas
HARP	Heartland Area Redwater Project
H_2S	hydrogen sulphide
ICO_2N	Integrated CO_2 Network
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
Mt	megatonne (million metric tonnes)
MW	megawatt
MMV	monitoring, measurement and verification
NRTEE	National Round Table on the Environment and the Economy
OOIP	original oil in place
RFP	request for proposal
R&D	research and development
U.K.	United Kingdom
U.S.	United States
WASP	Wabamun Area CO_2 Storage Project
WTI	West Texas Intermediate

Executive Summary

The Government of Alberta's plan to address greenhouse gas (GHG) emissions through the widespread implementation of carbon capture and storage (CCS)[1] technologies is achievable. This is important not just for Alberta but for the world. CCS as a mitigation measure can make a meaningful impact on global GHG emissions. The work of the Alberta Carbon Capture and Storage Development Council confirms this potential and, more importantly, it outlines the blueprint required to make this potential a reality.

There is a strong consensus that CCS will be necessary to dramatically reduce emissions globally. The importance of CCS has been reaffirmed by a new study from the International Energy Agency, *Carbon Dioxide Capture and Storage: A Key Carbon Abatement Option* (October 2008). The study indicates that CCS can deliver cost-effective emissions reductions, but that governments and industry must come forward to finance large-scale CCS demonstrations and work together more widely.

In Alberta, CCS is the key to the continued development of our vast energy resources in the carbon-constrained future we face – allowing us to help to meet the world's long-term energy demands while significantly reducing GHG emissions. We are well positioned to make a significant contribution to improving CCS technologies and building full-scale CCS facilities and infrastructure. To advance CCS in Alberta, however, the right economic balance will be required. To achieve widespread adoption while maintaining its international competitiveness, Alberta needs fair carbon dioxide (CO_2) emission compliance costs and financial support.

The Government of Alberta's $2-billion CCS fund, announced in 2008, is poised to catapult Alberta into a global leadership position in CCS. This program will help to ensure that a first wave of three to five CCS demonstration projects is built here in Alberta, through joint government and industry collaboration. These projects will be insufficient to ensure that the province reaches its longer-term 2020 and 2050 GHG reduction goals, but they will create important momentum.

The Council's work has led to significant refinement of the capital and operating costs of CCS over estimates that were previously available to us. Initial investments in CCS will be expensive. Costs will decline as expertise is gained in the field. Increased expertise coupled with commodity price improvements could deliver manageable costs to industry – costs comparable to other GHG reduction compliance alternatives. To accelerate progress toward Alberta's reduction objective via CCS of 25 to 30 megatonnes (Mt) of CO_2 per year by 2020, there is a need to remove the financial disadvantage created by CCS until such time as cost improvements and/or higher compliance costs level the field for industry worldwide.

[1] Carbon capture and storage is a technology that separates carbon dioxide from other gases in coal-fired power plants and other large-emission sources and stores it kilometres deep underground instead of releasing it into the atmosphere.

How much it will take to fill this "financial gap" depends on a number of factors, including the pace of CCS development, the viability of enhanced oil recovery (EOR) markets, compliance costs in Alberta, and costs in competing jurisdictions. We estimate that an investment of between $1 to $3 billion per year from the governments of Alberta and Canada will be required to promote further CCS projects after the first wave of demonstration projects. Industry will likewise need to shoulder significant additional investment.

Energy consumers will ultimately bear a large share of the burden of the costs of CCS. Albertans, as energy consumers, need to understand CCS technology and how it will help to contribute to our sustained prosperity. Investment in cleaner energy production, supported by technologies like CCS, is about investing in an economy capable of sustaining itself into the future. The Council has found that a very solid long-term business case exists for financial support for CCS.

One of the ways CCS will spur economic benefits is through EOR – the storage of CO_2 in oil reservoirs spurring incremental oil production. Assuming a reference price of $75 per barrel of oil, the Council estimates that sufficient EOR capacity exists in Alberta to potentially store 450 Mt of CO_2 and produce an additional 1.4 billion barrels of oil from conventional reservoirs; this represents a doubling of Alberta's conventional oil recovery. This incremental production would translate to $105 billion of revenue over the life of the development, potentially generating from $11 to $25 billion in additional provincial royalties and taxes. We will all share in this economic benefit.

Oil is only part of the story. Alberta has coal reserves with twice the energy content of even its vast oil sands reserves. Sustainable, coal-fired electricity generation is important to Alberta's continued competitiveness in an integrated North American energy market – but without CCS, the acceptability of power from coal will be far from assured. CCS offers the potential to address coal's carbon footprint, thus enabling its use in a carbon-constrained future.

Further, our leadership in CCS will generate opportunities for Alberta to participate in significant markets for CCS know-how in North America, in Europe, and in the rapidly developing Asian energy markets.

The Council is pleased to observe that Alberta's regulatory preparedness for the first CCS projects is well advanced. There remains a need for GHG emission regulatory and policy clarity to reduce the financial uncertainties that exist in large-scale, long-term, industrial CCS developments – addressing issues including pore space tenure, long-term liability, safety, CCS governance and pipeline infrastructure development options and approaches. The Council finds that CCS safety risks are manageable; some important suggestions for improvement are noted in the report.

CCS research and technology priorities for Alberta have been identified and specific initiatives have been recommended. Significant additional resources are required ($100 to $200 million per year) to enhance current research and technology activities and improve the viability of commercial CCS and related technologies.

Climate change is a global problem that will be addressed with many different policy approaches. Our focus has been on CCS as it has the highest potential in the context of the Alberta economy. It is important to recognize that CCS is not a "silver bullet." As is correctly pointed out in the *Provincial Energy Strategy* (2008)[2] and *Alberta's Climate Change Strategy* (2008), efforts on CCS should be complemented with policies including wise energy use and continued efforts to green our energy production. Nevertheless, we are confident in predicting that investments from the governments of Alberta and Canada to ensure widespread CCS adoption will be accompanied, in the long term, by impressive economic and environmental returns.

CCS development will require an effort sustained over many decades. It will demand long-term thinking from our leaders. Government and industry will need to stay the course irrespective of economic uncertainties – including those brought about by the current downturn. Ultimately, CCS will enable our province, and our country, to play a substantial role in addressing the environmental and economic challenges we face globally.

This report is not an official government document and may not necessarily reflect the views of the Government of Canada or the Government of Alberta.

CCS lies at the intersection of energy, the economy and the environment and Alberta is well positioned to make a significant contribution to advancing CCS technologies and building full-scale CCS facilities and infrastructure.

[2] Launching Alberta's Energy Future – Provincial Energy Strategy, 2008

Key Conclusions and Recommendations

CCS will be necessary if we are to dramatically reduce CO_2 emissions globally. To advance CCS in Alberta, the right economic balance is required. Alberta needs competitive CO_2 emission compliance costs in order to remain an internationally competitive jurisdiction. Alberta also requires a program that supports CCS financially in order to accomplish the acceleration of its widespread adoption.

A UNIQUE OPPORTUNITY

- CCS represents a unique opportunity to balance future energy needs and continued economic growth, while making a significant contribution to meeting Alberta's, Canada's, and the world's GHG emission reduction targets. Alberta has made a bold commitment to addressing climate change. Rapid deployment of CCS is needed if the province is to reach its GHG reduction goals.

A COMPLEX CHALLENGE

- The development of CCS on a widespread basis will take time, and the technology choices, economics, financing, and policies required are complex. There is a role for both government and industry in managing its development. CCS is expensive and currently uneconomic. CCS costs are site-specific and vary widely. They range from $70 to more than $150/tonne. Over and above any potential compensation available to industry, deploying CCS currently carries a financial disadvantage of up to $100/tonne.[3]

- Using CO_2 in enhanced oil recovery (EOR) projects has great potential, but EOR projects are front-end capital intensive. To be economic, these projects require significantly lower prices for CO_2 than the expected costs of CO_2 capture and transportation, even at oil prices above $75 per barrel. Revenue from EOR operations can support some of the costs of CCS, but a gap will remain as capture costs exceed the price that EOR operators can economically afford.

- To move toward Alberta's emission reduction objective of 25 to 30 Mt/year of CCS by 2020, there is a need to offset CCS's financial disadvantage until such time as cost improvements and/or higher compliance costs level the playing field for industry worldwide. The level of financial investment that will be required from the governments of Alberta and Canada depends on the pace of CCS development, the viability of EOR markets, compliance costs in Alberta and costs in competing jurisdictions. Industry will also need to shoulder additional investment.

- The market for CO_2 will be fragile due to the large capital investments required and the substantial volumes of CO_2 that will be captured with each new plant. During the early stages of CCS development, each new plant that begins to capture CO_2 will add a significant volume of CO_2 to the market, relative to the size of the existing market.

[3] The financial disadvantage, or gap, is defined as the net cost of CO_2 abatement, including an adjustment for revenue from any sale of CO_2, a deduction for other GHG compliance costs which can be avoided by the capture company, and consideration for the emissions of CO_2 that come from the new energy use by the capture and transport facility.

- It is difficult to predict the future economic conditions in Alberta including the many variables such as cost of capital, labour costs and the price of carbon. Government support for CCS needs to be steadfast and clear. It also needs to be sufficiently flexible to adapt to new economic conditions that may arise over the coming decades.

A COMPELLING RETURN

- It is the Council's view that government contributions to CCS will ultimately lead to increased royalty and tax revenues from a sustainable and growing economy including incremental EOR production, continued oil sands development, a higher level of value-added processing within the province, and more competitive power prices due to the inclusion of coal in Alberta's power generation mix.

- There is a business case for the Government of Alberta to continue to support CCS beyond the current $2-billion CCS fund. Alberta can significantly reduce its GHG emissions while securing markets for our oil sands products, extracting value and a dependable supply of electricity from our coal resource, enhancing our value-added opportunities and increasing EOR and wealth for all Albertans and Canadians.

  - At $75/barrel, sufficient EOR capacity exists in Alberta to potentially store 450 Mt of CO_2 and produce an additional 1.4 billion barrels of oil from conventional reservoirs. Developing new technology for heavy and immiscible fields, coupled with higher oil prices at $125/barrel, could increase CO_2 demand to over 35 Mt/year and result in the incremental recovery of 3.5 billion barrels of crude oil. This would more than double Alberta's recoverable conventional oil reserves. The estimate is 60 per cent higher than past estimates due to the potential for EOR in heavier and immiscible reservoirs.

  - An incremental 1.4 billion barrels of oil production would translate to $105 billion of revenue at $75/barrel oil prices over the life of the development, potentially generating between $11 and $25 billion in additional provincial royalties and taxes. Clearly, the use of CO_2 for EOR has the potential to unlock significant additional revenues for Albertans.

  - A significant percentage of the available cash flow from each integrated oil sands project flows to governments and fuels the social wellbeing of Canadians.[4] Using a portion of these revenues to support CCS to meet the objective of sustainable development can result in ongoing economic growth and wealth creation.

  - Alberta's vast coal resources provide a competitive advantage to Alberta's economy. Deployment of CCS within the coal-fired power industry is critical to retaining competitive electricity prices for Albertans and allowing the continued use of coal in a carbon constrained environment.

[4] The oil sands industry is expected to generate $123 billion in government revenue by 2020, based on a forecast of industry investment of $100 billion over the same time period. This government share includes royalties (which only the Government of Alberta receives) and personal, corporate, property and sales taxes to all three levels of government across Canada. The largest portion, 41 per cent ($51 billion) will go to the federal government, with 36 per cent ($44 billion) for the Government of Alberta, and nine per cent ($12 billion) for other provincial governments. Municipal governments will receive the remaining 15 per cent ($17 billion). In this way, revenues from oil sands development will be available to improve the quality of life of all Canadians by helping to pay for public infrastructure and essential social services such as health care and education [Canadian Energy Research Institute, (CERI), Economic Impacts of Alberta's Oil Sands, 2005].

- Alberta has significant value-added opportunities in the secondary processing of our resources, such as upgrading and refining. CCS is a key to unlocking this value sustainably in a carbon-constrained world.

POLICY AND REGULATORY ENABLEMENT

- Regulatory and policy clarity should be solidified by the end of 2009 in order to ensure that the momentum of the initial $2-billion CCS fund for large-scale CCS projects, to be built by 2015, is followed by more widespread adoption of CCS. This support will result in substantial emission reductions, increased oil production, and continued economic growth.

- Larger scale CO_2 activity, like any energy development in Alberta, will require stakeholder involvement to address concerns associated with the safe, orderly, and environmentally appropriate construction of capture, transportation and injection facilities. The Energy and Resources Conservation Board (ERCB) has about 25 years of experience with acid gas re-injection and small-scale CO_2 transportation. ERCB has a regulatory framework in place to address the public safety, environmental protection and resource conservation aspects of small and larger scale CCS development.

- Issues of pore space tenure and longer-term storage liabilities can be effectively dealt with by Alberta to ensure CCS is developed through prudent and safe management practices in the longer term. Clarity is needed now, however, to ensure that the first wave of projects built under the Government of Alberta's $2-billion CCS fund will have regulatory certainty.

TECHNOLOGY ENABLEMENT

- Alberta has already contributed, and can continue to significantly contribute, to global CCS research and development (R&D) efforts. Knowledge gained from Alberta's "in the ground" piloting and large-scale demonstration of technologies and processes will be invaluable to these R&D efforts. Alberta's current CCS funding will result in three to five initial projects which, in combination with other CCS demonstrations around the world, will lead to a better understanding of the costs for the technology and contribute to global knowledge and pragmatic process solutions for reducing GHG.

- The timeframe to achieve commercial-scale CCS with reasonable costs is 15 to 20 years. New or improved lower cost capture technologies need to be aggressively developed and deployed taking advantage of, for example, the technology platforms of CCS and gasification as identified in the *Provincial Energy Strategy* (2008). Alberta's experience suggests that, for successful government-industry models[5] to share costs and risks of "game-changing" technologies, $100 to $200 million per annum is needed as a base level for government-industry expenditures on research and adapting technology to Alberta's needs.

[5] Based on Alberta Energy Research Institute (AERI) experience with the integrated programs in hydrocarbon upgrading and gasification with CCS.

- Pipeline transport and storage of CO_2 in Alberta's CO_2 EOR-amenable oil reservoirs is a proven technology. This is supported by: the success of the Joffre EOR project, near Red Deer, which has been in operation for more than 25 years and has sequestered over 1.2 Mt of CO_2; the seven-year history of the Weyburn project in Saskatchewan; and 25-plus years of CO_2 EOR experience in the U.S., where 40 Mt of CO_2 is currently injected yearly.

- CO_2 pipelines have a long, safe track record in the U.S. Several approaches to pipeline development in Alberta can generate the benefits of a "network," while ensuring the discipline and efficiency of market mechanisms.

- Depleted gas reservoirs have the potential to store up to 1,500 Mt of CO_2, and saline formations over 3,000 Mt of CO_2 – enough space for decades of the expected CO_2 capture volume. Western Canadian oil and gas operators have significant experience with the injection of CO_2 and hydrogen sulphide (H_2S), known as acid gas, in a wide range of injection projects. Gas reservoirs and saline formations both require focused, large-scale assessment and demonstration over the next 10 years in order to ensure selection of the best large scale injection candidates.

THE KEY INGREDIENT: SUSTAINED WILL

- The Government of Alberta's $2-billion CCS fund provides a kick-start to full-scale CCS implementation. Alone, it will not deliver the government's longer-term CCS and GHG emission reduction goals. Significant additional investment will be required from the federal and provincial governments and industry to further develop the technology and capture additional CO_2 over and above the 5 Mt annually sought from the initial wave of funding. In particular, promotion of further CCS projects after the 2015 period will be needed to meet 2020 emission reduction.

INVESTMENT RECOMMENDATIONS

- Adopt a "Pay-for-Results" approach to providing support for CCS, under which government support will be linked to volumes of CO_2 captured. Pay-for-Results will send a clear and strong policy signal to industry that there will be adequate support for incorporation of CCS into new projects. The approach is expected to result in increased investment and a net positive contribution to Alberta's economy and government balances.

- Continue to work with industry to seek synergies between CCS developments in order to achieve economies of scale and reduced infrastructure costs. Funding and policy mechanisms should be directed to advancing less expensive cost capture technologies and to identifying and testing both depleted gas reservoir and saline formation storage.

- Additional technology funding should be directed to testing of CO_2 EOR in immiscible light and heavy oil pools, which could increase the size of the EOR market by 50 per cent.

POLICY AND REGULATORY RECOMMENDATIONS

- The Government of Alberta needs to move expeditiously to put in place any necessary CCS legislation, regulations, or operational requirements related to pore space tenure and long-term storage liability. The Council recommends that the ERCB should ensure that it has appropriate resources and processes to review CCS applications in a timely manner.

- To advance widespread adoption of CCS, a clear set of principles against which implementation options are evaluated should be developed. These principles should promote market mechanisms, ensure appropriate risk sharing, provide sound incentives and ensure administrative feasibility.

- To maintain Alberta's competitive position and support the value-added activity that is targeted in the *Provincial Energy Strategy* (2008), the Council recommends that Alberta ensure its compliance obligations are not greater than those of other jurisdictions.

- Given the challenges of introducing the significant cost of CCS into the deregulated electricity market in Alberta, we recommend that the Alberta Department of Energy consider potential regulatory mechanisms that would have the effect of not placing those implementing CCS at a competitive disadvantage.

- The development of requirements for "CCS-ready" status should be further assessed based on the results and knowledge garnered from the first round of projects developed from the $2-billion CCS fund.

- Recommendations for a CO_2 management policy framework are included in the Regulatory and Governance Considerations section of this report to address long term liability issues of CO_2 storage. Aspects of this framework include:

    ➢ Project life requirements

    ➢ Post-closure requirements

    ➢ Monitoring, measurement & verification requirements

    ➢ Management framework costs

- An ongoing CCS governance approach is needed and should evolve over time in concert with the state of development of CCS technology in the province. The Council offers a set of principles and two governance options for the Province to consider.

- Regulators and project developers need to address potential stakeholder concerns regarding safety, environmental impact and the orderly development of CCS infrastructure. To ensure that Alberta continues to proactively address safety issues related to CCS, it is recommended the Canadian Standards Association (CSA) be approached to update and incorporate CO_2 transportation and storage in the applicable national standards.

- The Province should ensure that initial CO_2 pipelines, where possible, are designed so they can be incorporated into an efficient provincial network through the use of market and regulatory mechanisms as required.

TECHNOLOGY RECOMMENDATIONS

- A review of technology requirements for CCS has identified a set of R&D priorities for Alberta. These priorities are detailed in the R&D and Technology Needs section of this report and provide a focal point for technology investment in the future. Aspects of this focus include the following:

    - The focus should be on capture R&D with its high potential for cost savings, and Alberta-specific storage. The work should proceed with international collaboration to avoid duplicative work.

    - The Canadian CO_2 storage atlas should be completed as soon as possible.

    - The delineation and testing of saline formations for CO_2 storage should be promoted with a portfolio approach to study areas and projects.

    - Research on the application of CO_2 for EOR to Alberta's immiscible and heavy oil reservoirs should be advanced.

Alberta has the potential to make a difference in not only meeting the world's energy needs but also contributing to the development of leading-edge CCS emission reduction facilities and technologies.

1.0 Introduction

This report provides a final set of conclusions and recommendations from the Alberta Carbon Capture and Storage Development Council. The Council was appointed in April 2008 to provide recommendations to accelerate the development of CCS in Alberta. The Council's mandate and membership are provided in the appendix of this report.

2.0 CCS Strategic Context

The engine of economic growth and one of the key pillars of Alberta's high standard of living is the continued development and production of its vast energy resources. The future development of these resources must take place in a manner that recognizes and responds to the carbon-constrained future that likely faces society.

CCS represents an opportunity to make significant progress on sustainable development of Alberta's resources. There is a need to grow Alberta's CCS capabilities and projects as soon as possible.

CCS is recognized globally as a technology possessing the potential to dramatically reduce GHG emissions. There is agreement among key stakeholders in Alberta that CCS holds the promise to significantly contribute to Alberta's long-term climate change strategy provided the economic and policy hurdles confronting CCS can be overcome. While contributions from renewable energy development and conservation are an important part of Alberta's carbon intensity reduction plan, some 70 per cent of Alberta's potential reductions are foreseen to arise from CCS.

If CCS is going to make a substantial contribution to Alberta's future, immediate steps towards fostering CCS development are needed. Factors that influence Alberta's long-term environmental and economic performance – our long term sustainability – include:

- the continued global demand for energy;
- the continued growth in importance of sustainable energy development;
- the significant growth planned for Alberta's energy production facilities in the next decade;
- assurance for all Albertans and key stakeholders that oil sands and thermal and electrical power generation development can proceed sustainably; and
- a growing global market for CCS technologies.

The immensity of Alberta's energy resources, their planned development, and their emissions impact are borne out in a number of statistics:

- Canada's estimated oil reserves are 179 billion barrels – the second largest in the world after Saudi Arabia. Approximately 174 billion barrels lie in the oil sands.[6]
- Alberta's coal reserves are 33 billion tonnes – 1,000 years of production at current rates.
- Oil sands production is expected to almost triple to about three million barrels per day by 2015 with capital expenditures of over $80 billion through this period.[7]
- Oil sands GHG emissions would more than double by 2015 without CCS implementation. Significant decreases in emissions intensity are possible through large-scale implementation of CCS.

Economic growth provides jobs and opportunities not only in Alberta but across Canada. Alberta has the opportunity to be a leader in sustainable economic growth in Canada, in North America, and globally.

Global demand for energy continues to rise as the economies of China and India grow exponentially and the U.S. strives to meet its goals of energy demand, energy security and sustainable development.

The following graph from a 2008 National Round Table report illustrates the relative importance of CCS to Canada's and Alberta's initiatives to reduce GHG emissions.[8]

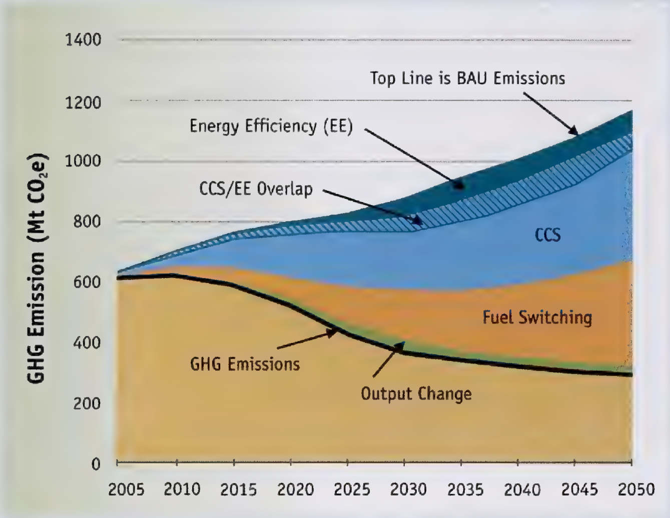
The development of CCS on a widespread basis will take time, and the technology choices, economics, financing, and policies required are complex

[6] U.S. Energy Information Administration

[7] National Energy Board

[8] National Round Table on the Economy and the Environment Report

Getting to 2050: Canada's Transition to a Low-emission Future



National Round Table on the Environment and the Economy (NRTEE) Note: CCS represents the carbon capture and storage wedge. CCS/EE represents the carbon capture and storage (CCS) and energy efficiency (EE) overlap where both CCS and EE work in tandem to reduce emissions. The fuel switching wedge represents the contribution of switching from coal to oil products to natural gas to electricity; this portion also includes the contribution of renewables (wind, hydroelectricity, etc.) and nuclear power. The output wedge represents the GHG reductions due to lower physical output. Chart is based upon a scenario of carbon prices greater than $200/tonne by 2030. BAU emissions stands for Business As Usual.

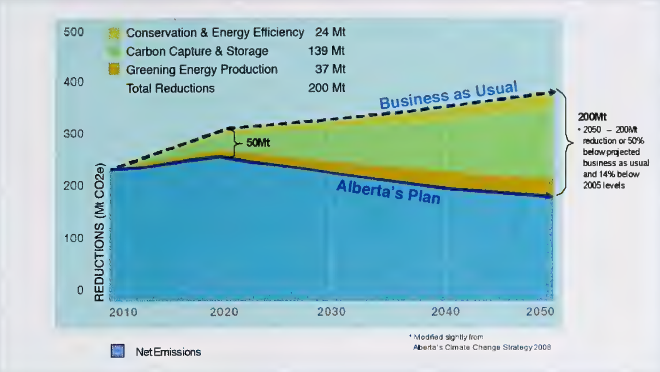
Source: **National Round Table on the Economy and the Environment**

CCS represents the largest point source contribution to emission reduction, with the other wedges requiring contributions from many distributed actions across Canadian society. On a comparative basis, even in a worldwide economic downturn, CCS can be a major contributor to reducing GHG in Canada and the world.

There is a burgeoning market developing for CCS technologies globally. Expertise developed at home in Canada will be exportable worldwide in much the same way that Canada's and Alberta's oil and gas development skills are at work in all parts of the world.

In January 2008, the Government of Alberta released its *Climate Change Strategy*, which outlined the Province's longer-term targets to reduce GHG emissions. A reduction in emissions by 200 Mt/year by 2050 over business-as-usual is required. More significantly, 139 Mt/year (or approximately 70 per cent of the emission reductions) would be achieved by implementing CCS on an extensive basis in Alberta's oil sands, in its power sector, and in industrial facilities.

Alberta's Reduction Commitments*



Source: **Alberta 2008 Climate Change Strategy**

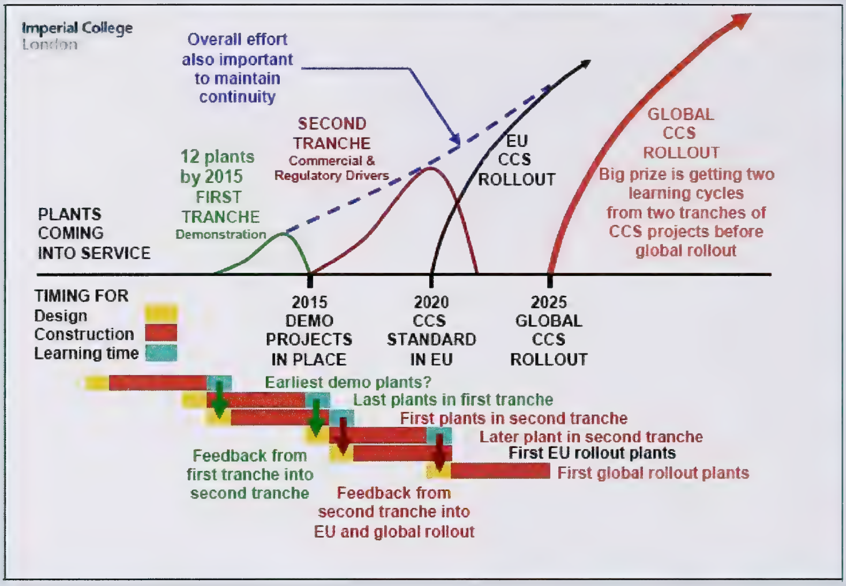
The task of developing a broad-based application of CCS in Alberta is immense. As a significant initial step, Alberta announced in July 2008 a $2-billion fund to kick-start CCS implementation in Alberta.

It is important to note that a significant emission reduction contribution of 30 per cent of Alberta's target has been identified from sources including conservation, energy efficiency, low carbon fuels, and greening energy production. CCS is an important technology to bring about emission reductions but it is only one of a number of emission reduction approaches that our society must advance in order to meet the challenges of a carbon-constrained world.

The development of CCS requires a collaborative approach due to the complex interaction of economics, technology and regulations. A collaborative approach among key stakeholders has proven important in a number of large infrastructure developments in Canada including: the construction of the national railroad; the initial scale-up of oil sands development (Syncrude Canada Ltd.); and technology efforts to reduce the cost of oil sands production (Alberta Oil Sands Technology and Research Authority).

The situation in Alberta is mirrored elsewhere around the world; the European Union (EU), the United Kingdom (U.K.), the United States (U.S.) and Australia have all signalled their intent to employ CCS for GHG reductions. In all these jurisdictions there is a challenge as to how to get to the next stage of the development. The installation of large-scale CCS facilities can't be justified by the private sector when the level of GHG reductions expected can be more cost effectively managed through purchasing offsets or other actions.

CCS has the potential to transform Alberta's energy sector's long-term environmental sustainability and facilitate its continued resource development. The following graph illustrates the longer-term commitment needed to bring about the technological and environmental change given the magnitude and complexity of CCS.



Source: **Dr. Jon Gibbins, Imperial College London, United Kingdom**

Some of the attributes of CCS technology today include:

- The technology can be compared to the state of oil sands technology in 1980 – embryonic.
- Historically, we have experience that demonstrates that focused effort and a strong government-industry partnership will solve large structural energy technology challenges.
- Hands-on CCS technology experience at scale is very limited globally, and therefore cost estimates, technology selection choices, and performance expectations all have a high degree of uncertainty.
- There is enough understanding to begin developing full-scale CCS projects, and the growing base of developmental work will continue to bring about new technology advancements.

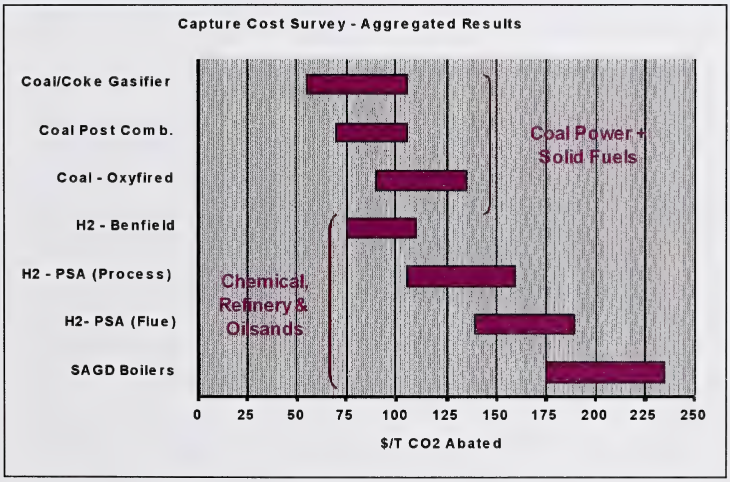
3.0 CO_2 Capture, Storage, and Infrastructure

3.1 CO_2 Capture

CO_2 capture represents 70 to 90 per cent of the overall costs of the CO_2 capture, transport and storage sequence. In addition, capture is the step with the least amount of actual technology application and, accordingly, it is the area where there is significant cost uncertainty.

To better understand the cost of capture, a survey was provided to 27 companies known to be interested in CCS. Many of these companies were involved in preparing proposals to tap the Government of Alberta's $2-billion CCS fund. Data were collected on more than 20 facility concepts from 10 companies and public-source information was also used to fill in parts of the cost survey. To preserve the confidentiality of company information, all data were held by an independent consultant and the Council was provided with aggregated results.

CO_2 Capture – Cost Estimates



Notes:
- Based on over 10 interviews, and 20 different facilities. Cost ranges due to geographic, technical and greenfield vs. retrofit considerations
- Excludes pipeline, storage costs, credit from EOR sale, avoided offset purchase
- Capital costs in 2008 C$, Operating costs levelized at 2008 real $ cost (10% time value discount)
- "CO_2 Abated Cost" includes cost penalty for make up production and incremental CO_2 emissions from energy use (fuel and electricity)

SOURCE: Ian Murray and Co. Ltd.: Alberta CO_2 Capture Cost Survey and Supply Curve 2008

The preceding chart shows the cost ranges for the technologies likely to be used at power, oil sands and chemical emission points in Alberta. Past efforts to estimate CCS costs have been unreliable due to the pace of cost escalation and the site-specific nature of capture plants. The estimates collected through our survey are felt to be more reliable, as they were provided by companies preparing to invest in facilities and were not theoretical studies.

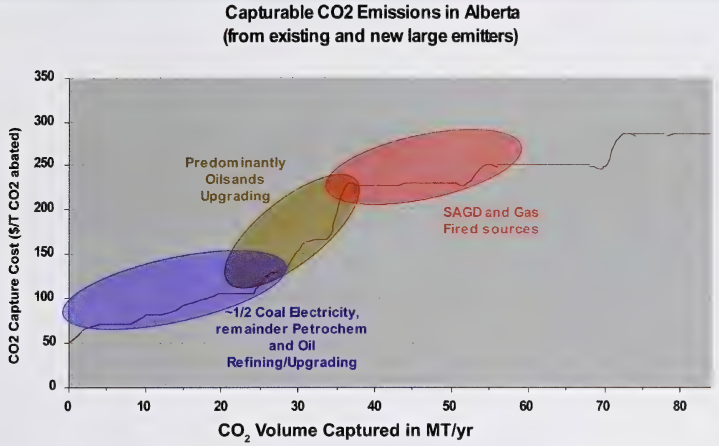
The main factors influencing the capital costs of CCS are steel, concrete, engineering services, purchased equipment and labour. The overall costs presented also include the cost of energy, operations and maintenance over a 25-year facility life. All information is presented on a CO_2-abated basis, which accounts for emissions associated with the energy required to run the capture plant. This adjustment increases CCS costs by 20 to 30 per cent. The costs are current as of the summer 2008, a time at which construction costs in Alberta had experienced several years of escalation. Costs may moderate somewhat based on the present-day weaker economic outlook.

The chart illustrates the wide range of capture costs expected even within a technology category, demonstrating how site-specific any accurate analysis must be. In general, survey data suggest that retrofit projects are more costly. Coal-fired electricity plants capture costs range from $60 to $150/tonne of CO_2 abated and generally have lower capture costs than refinery and oil sands facilities. This result aligns with international cost studies; it is attributable to the higher concentrations of CO_2 in the flue gas and the economies of scale available at coal-fired power plants.

Coal/coke gasifier CO_2 capture costs appear to be among the lowest, but other economic factors need to be taken into consideration. The chart shows the incremental cost of CCS once a gasifier has been economically justified. When analyzed on an all-in-cost of supply basis for electricity or hydrogen, gasifiers are more expensive than coal plants with back-end CO_2 capture. Gasifiers, which would replace natural gas hydrogen plants, generate twice as much CO_2 per unit of output. Gasifiers have yet to be widely demonstrated for the oil sands.

Using these cost data, a supply curve from all sources was generated for the year 2020. The curve encompassed retrofits as well as the expected number of new build oil sands and power generation facilities. The oil sands growth rate was derived from summer 2008 data generated by the Canadian Association of Petroleum Producers (CAPP). Given the current economic downturn, and recent announcements of project deferrals, the oil sands growth rate is now expected to be flatter. The growth in new power generation was prepared in consultation with the power sector.

CO_2 Capture Cost Curve



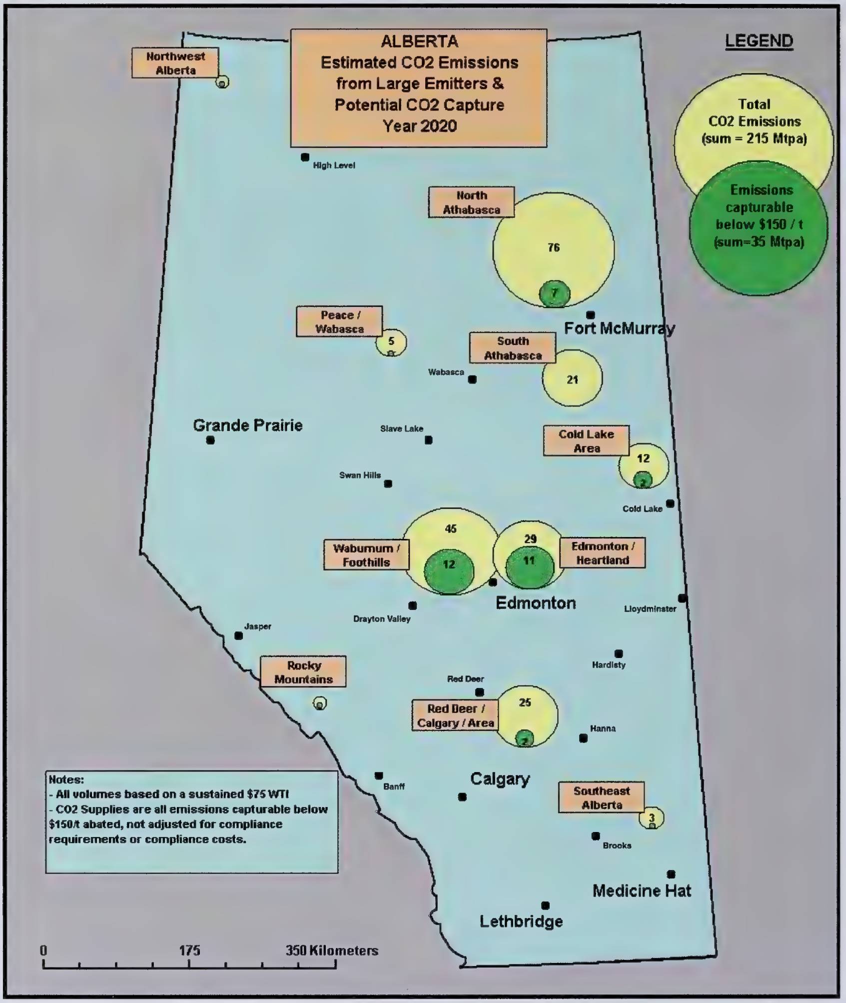
Notes:
- Includes all facilities estimated to be operating in Alberta by 2020 (existing and yet to be built)
- Reflects only capture costs, not pipeline or storage costs, nor credit from EOR sale, nor avoided offset purchase
- Capital costs in 2008 C$, Operating costs levelized at 2008 real $ costs for fuel and operations
- "CO_2 Abated Cost" includes penalty for make up production and incremental CO_2 emissions from energy use (fuel and electricity)

SOURCE: Ian Murray and Co. Ltd.: Alberta CO_2 Capture Cost Survey and Supply Curve - 2008

The overall capture cost curve ranges from 2 Mt/year at $50/tonne to 50 Mt/year at $225/tonne. The amount of CO_2 as of 2015 will not be directly driven by lowest cost sources, but more a function of retrofits possible at existing facilities, and a few new oil sands plants with associated capture. In general, greenfield CCS facilities have a lower overall cost.

These capture data can also be considered from a geographic perspective. As shown in the following map, most of the supply will be generated from the vicinity of Fort McMurray, Fort Saskatchewan and Wabamun. The cost estimates in this chart will change as new projects designed for the increasingly carbon-constrained world come on stream.

Alberta Potential CO_2 Supply Map



Source: **Ian Murray and Co. Ltd., Alberta CO_2 Capture Cost Survey and Supply Curve 2008**

3.2 CO_2 Storage

3.2.1 Enhanced Oil Recovery

There is a strong incentive in Alberta to ensure that CO_2 from CCS is employed in EOR applications. The approach involves injecting CO_2 into mature oil fields to improve their production rate. Ultimate oil recovery can be improved by three to 15 per cent or more while ensuring the CO_2 remains stored in geologic formations that have safely held hydrocarbons for hundreds of millions of years. In the U.S. CO_2 EOR has been proven over the past 30 years and has grown to a market size of 40 Mt/year of CO_2. CO_2 for EOR in the U.S. is produced predominately from natural high-purity CO_2

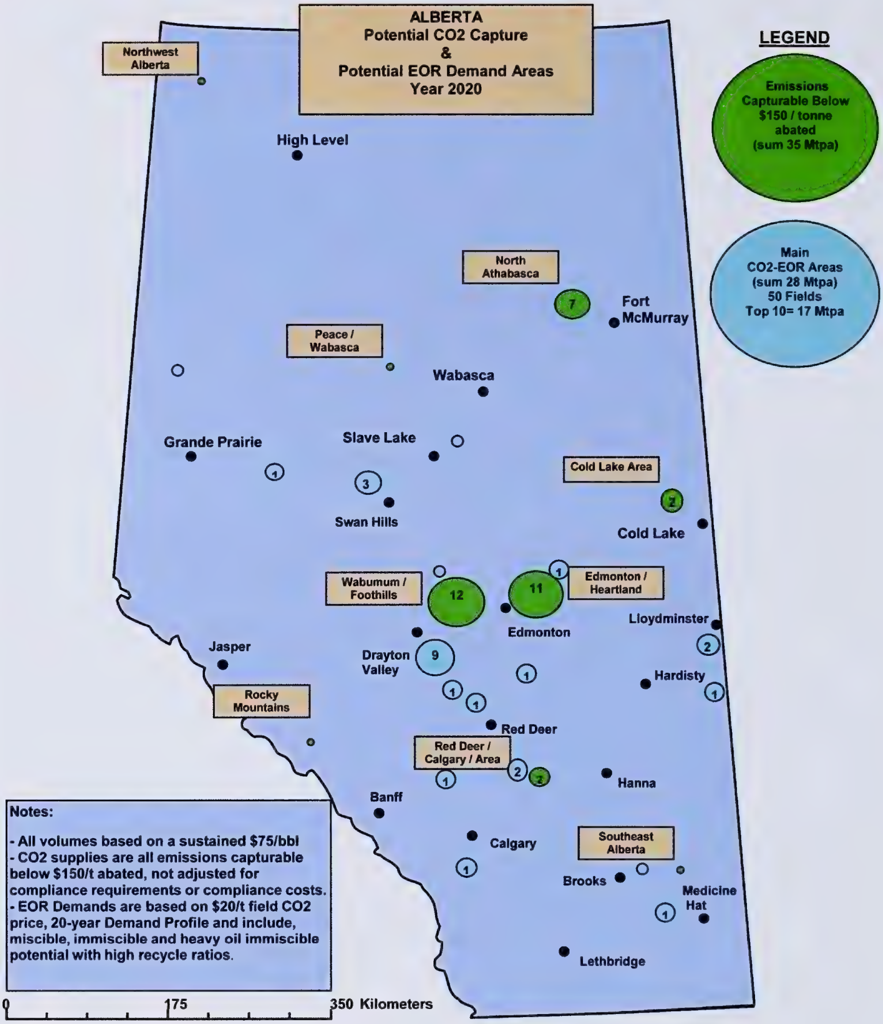
reservoirs, transported by pipeline, and injected in mature oilfields. The operation does not have the cost challenges – or the environmental benefits – that capturing CO_2 from industrial sources entails. Industrial CO_2 that is captured, dehydrated, compressed and utilized in EOR projects is generally required to have a CO_2 purity of at least 95 per cent. The remaining impurities in a CO_2 capture stream are an important consideration, since some impurities have the potential to cause operational issues or adversely affect reservoir performance. For example, introducing H_2S as an impurity from a CO_2 capture stream into an existing sweet oil pool would not adversely impact reservoir performance, but it could potentially cause metallurgical and operational issues at surface. Inert gases such as nitrogen, in small quantities, are not likely to have a detrimental impact on EOR operations; however, higher concentrations of nitrogen can impair reservoir performance by reducing the miscibility of CO_2 into the reservoir fluids.

It should be noted that the Council did not look at enhanced gas recovery, or enhanced coalbed methane recovery. These approaches could add to the extent of suitable CO_2 permanent storage locations, but they are much less proven than EOR so they were not considered significant for early deployment.

In order to objectively address the storage potential of EOR in Alberta, an independent study was undertaken by a CO_2 EOR reservoir engineering consultant to determine the potential demand for CO_2 by EOR over a range of oil prices and CO_2 purchase costs. The study expanded upon prior work by reviewing a number of reservoirs previously considered unsuitable for conventional CO_2 EOR because the oil was too heavy, the reservoir was not deep enough or had poor rock quality, it responded poorly to conventional waterfloods, or it had been previously miscibly flooded with hydrocarbon fluids. In addition, capital and operating costs were updated with recent industry experiences from a number of CO_2 EOR pilot and commercial projects in western Canada. The study screened an initial 10,000 oil pools down to 591 potentially amenable pools. The performance of these pools was then evaluated using one of five generalized prototype reservoir models and then economically evaluated using a simplified cash flow model. The results are approximate and show the economic sensitivity of the pools to oil price and CO_2 purchase costs.

The study identified, at oil prices above $125 per barrel, the ultimate potential to recover an additional 3.5 billion barrels of oil, which would more than double Alberta's remaining established reserves of conventional crude oil, while providing the capacity to sequester more than 1,100 Mt of CO_2.

Alberta Potential CO_2 Capture and Demand Map

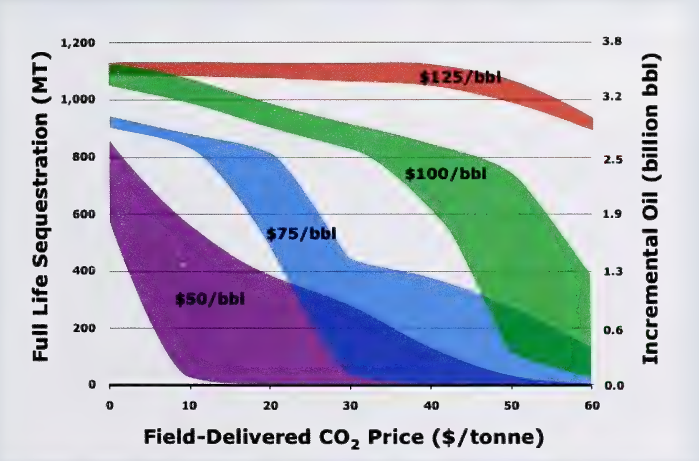


Source: Ian Murray and Co. Ltd., Alberta CO_2 Capture Cost Survey and Supply Curve 2008 and based upon EPIC Consulting Services Ltd. and Sproule, Alberta Enhanced Oil Recovery CO_2 Demand Study 2008

The preceding map illustrates geographically the potential sources and sites for CO_2 in EOR applications.

As shown by the following figure, the demand for CO_2 relies heavily on oil prices. At very high oil prices, EOR can pay more for CO_2. Oil prices must be sustainable at their levels since investments into CO_2 EOR require multiple years of investment of up front capital and commitments to CO_2 purchases. At low oil prices near $50 per barrel, the demand for CO_2 is weak and would not likely support a broad CO_2 EOR industry in Alberta without access to very low-cost CO_2.

CO_2 – EOR Sequestration and Recoverable Oil Potential

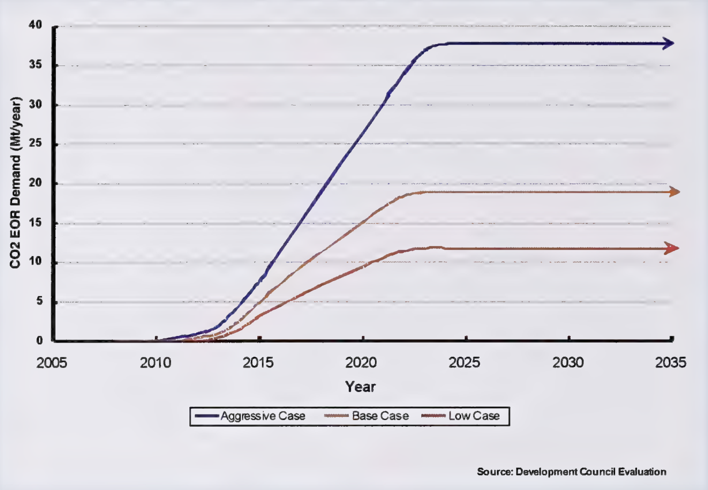


Source: **Based upon EPIC Consulting Services Ltd. and Sproule, Alberta Enhanced Oil Recovery CO_2 Demand Study 2008**

The demand curves for varied oil prices portray the estimated growth of EOR demand to a total of 700 to 1,100 Mt total over an estimated 30 to 40 years. This curve does not reflect the gradual build-up of demand as EOR progresses from pilot projects to demonstration and ultimately full projects.

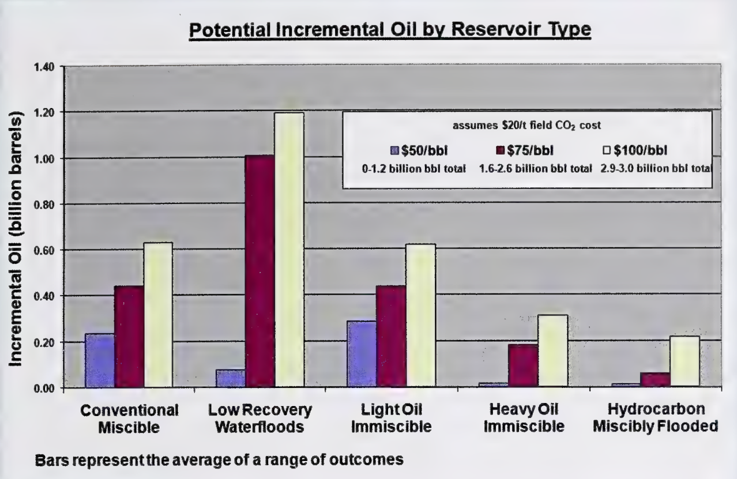
An estimate of the growth profile of the CO_2 EOR market is shown in the following chart. The Base Case curve is the most likely development pace; it could lead to 20 Mt/year of CO_2 demand for several decades. The Aggressive Case, where all the factors to promote CO_2 EOR are positive, including high oil price, modest CO_2 cost, and technical success from more challenging heavy and shallow immiscible fields, leads to about 35 Mt/year of demand.

Expected Profile of CO_2 EOR demand growth



There will be very little volume prior to 2013, as three to four years' time is required to develop capture sources, pipeline transport and complete EOR pilots. This curve also accounts for the natural ramp-up of production from a new basin area. The Aggressive Case growth curve is consistent with history in the U.S., where 40 Mt/year were achieved after 20 years of EOR growth, and an accelerated path for Alberta assuming that the technology and commercial viability of CO_2 EOR is better understood based on the knowledge transfer from successful U.S. and Canadian operations such as Weyburn.

Potential Incremental Oil by Reservoir Type



Source: **Based upon EPIC Consulting Services Ltd. and Sproule, Alberta Enhanced Oil Recovery CO_2 Demand Study 2008**

The figure above shows the five types of oil reservoirs screened for suitability to CO_2 EOR in Alberta at a low oil price of $50 per barrel, a moderate oil price of $75 and a high price of $100. It displays the relative contribution of each type to the potential incremental oil recoverable through CO_2 EOR. The figure reinforces that the economics of CO_2 EOR are challenged at low oil prices near $50 per barrel.

Conventional miscible projects are those pools that would be similar to most of the pools being flooded in Texas or the Joffre pool near Red Deer, which has been in operation for more than 25 years.

The next largest opportunity resides in those pools that have experienced waterflood recoveries below 25 per cent and are similar to the massive Pembina Cardium pool in Alberta or the Weyburn, Saskatchewan pool (which has been under CO_2 injection since 2000). The Pembina Cardium pool has 7.8 billion barrels original oil in place and the Weyburn pool has 1.4 billion barrels of original oil in place.

In the past, these candidate reservoirs have been considered less than optimal targets for EOR because of rock quality and poorer waterflood response. However, new technologies, such as horizontal drilling used at Weyburn, coupled with favourable royalty structures, have opened these large pools to development.

At an oil price of $75 per barrel and a field-delivered CO_2 price of $20/tonne, it is estimated that proven recovery techniques have the potential to add 1.4 billion barrels of incremental oil and sequester 450 Mt of CO_2.

The next largest opportunity resides in Alberta's light oil immiscible pools. These pools are normally not deep enough to achieve reservoir pressures required for optimal recovery with CO_2, but recent and limited projects in the U.S. are showing promise for this recovery technique. The size of the potential in Alberta and the apparent robustness of this technique across a range of oil prices warrant further study and piloting.

The other significant pool type that has potential at high oil prices is the heavy oil pools of eastern Alberta. Most of these pools have been deemed unsuitable for EOR using CO_2 because their shallow depth and the fact that heavier oil density is not optimum for miscible flooding. In addition, the low oil quality fetches a lower oil price and provides less revenue to recover capital costs. However, at high oil prices, with the development of new technology, or in a future environment with an over-supply of CO_2, heavy oil reservoirs could supply a value-added storage opportunity.

In summary, the ultimate potential recoverable oil and storage potential will be realized with the development and demonstration of new technologies that tap into the 50 billion barrels of conventional crude that currently remain in the ground in Alberta. In addition, the royalty and tax benefits to the governments of incremental oil production from EOR projects can provide a potential source of funds to help support continued CCS implementation.

3.2.2 Depleted Gas Reservoirs

Beyond the volumes potentially available via EOR, CO_2 storage options also include depleted gas reservoirs, which will become more abundant in Alberta over time. These pools have the following benefits:

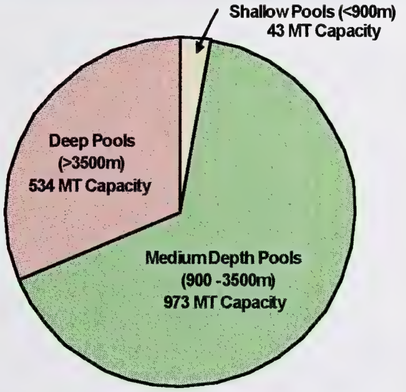
- Proof of containment – they have held hydrocarbons for hundreds of millions of years;
- Well-understood volumes since the gas that was removed was measured;
- Historical production rates provide a good understanding of potential CO_2 injectivity; and
- Existing infrastructure like wells and pipelines are in place.

Potential disadvantages include the following:

- Commercial conflict with conjoined oil or gas pools not yet drained;
- Risk of leakage from existing wellbores;
- Medium-term delays before reservoirs are completely empty of valuable natural gas; and
- Distance of large pools from capture sources increasing transportation costs.

A study by an independent consultant retained by the Council analyzed 920 pools in Alberta and identified 40 large pools that could hold more than 1,500 Mt of CO_2 at the end of their productive lives. Almost all of the storage capacity resides in medium to deep reservoirs, an attribute related to the fact that CO_2 at these depths is more compact as a dense-phase fluid. In addition to past assessments, this most recent study identified that 534 Mt of the total identified capacity resides in reservoirs deeper than 3,500 metres, as shown on the following chart.

Large (>10 MT) Depleted Gas Pool Storage Potential

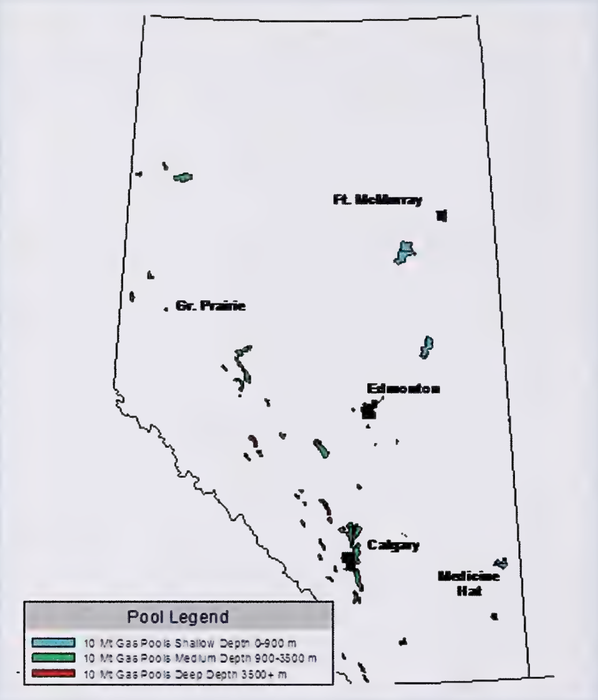


Source: RPS Energy 2008, Alberta Gas Pool Carbon Storage Estimate

The ultimate potential recoverable oil and storage potential will be realized with the development and demonstration of new technologies that tap into the 50 billion barrels of conventional crude that currently remains in the ground in Alberta.

The following figure shows the location of all the large pools in Alberta. In general, the greatest potential lies in a general southwest trend along the Foothills. The closest pools are a minimum of 50 and 150 kilometres (km) from the Wabamun power plants and the Industrial Heartland, respectively. Two large reservoirs lie within 60 to 230 km of Fort McMurray, but are not optimal as they are shallow and only offer 25 Mt of total storage. The closest medium-depth large pool is 380 km away, thus making this a challenging storage option for Fort McMurray sources.

Large (>10 MT) Gas Pools of Alberta



Source: **RPS Energy, Alberta Gas Pool Carbon Storage Estimate 2008**

By 2021, a total of 75 Mt of storage will become available in five large (more than 10 Mt) medium-depth reservoirs, but most of these targets are located in northwest Alberta and are not close to the larger emission sites. The largest increase in storage capacity in the medium-depth reservoirs becomes available after 2030, with the largest contribution of 235 Mt coming from the Kaybob pool located near Fox Creek. This pool is in close proximity to the large oil pools of Fox Creek and Swan Hills and could form the part of a future long term storage network.

In general, most depleted gas reservoirs do not appear to offer a near-term large-scale storage solution, but they eventually may form part of a storage system that is connected to a network built for the CO_2 EOR business. In addition, some smaller pools may be cost-effective as interim or buffer CO_2 storage to handle maintenance downtime on EOR project or operational work on the pipeline network.

3.2.3 Direct Storage

This category of storage location includes primarily deep saline formations and specifically excludes reservoirs that contain, or previously contained, hydrocarbons. These formations are so deep that the water residing in the pore space is too salty for human or agricultural uses. Previous work to assess storage potential in Alberta pertained to oil and gas reservoirs, with limited investigation of saline formations. However, there is high confidence that the previous estimate of three gigatonnes (Gt) of total storage capacity is a minimum that would be available. Until the initiation of field projects injecting large volumes of CO_2, it will be difficult to make conclusions about ultimate injectivity and capacity, but there is strong confidence that these storage locations will be adequate for decades of CO_2 volumes captured, even at levels exceeding 30 Mt/year. In particular, the basal Cambrian geologic zone has suitable characteristics due to its broad geographic coverage and, because it has very few well penetrations, its containment characteristics are enhanced.

The initial minimum requirement is that these reservoirs be deep enough to ensure dense phase CO_2 storage (deeper than 900 metres) and be separated from groundwater with one or more cap rock zones. The key success parameters for a storage candidate are as follows:

- Capacity – including depth, porosity, other fluids present;
- Containment – minimizes leakage from existing and future wells, and ultimate destination of any saline reservoir movement;
- Injectivity – geologic and rock properties affecting size and number of injector wells needed; and
- Location – access cost from emission points, public stakeholder presence.

The identification and confirmation of suitable direct storage reservoirs can be directly compared to petroleum exploration. Stages of progressively increased assessment will be required, with increasing confidence in success or rejection of a candidate to verify a given injection site. The stages include:

1. Initial regional geology and screening studies – selection of site candidates.
2. Testing of a specific storage location with geologic analysis using existing seismic and well data.
3. Confirming the analysis by acquiring new, more detailed information such as deeper drilling and injection testing.
4. Geochemical and geomechanical analysis of rock properties to predict impact of CO_2 injected.
5. Initiating injection with ongoing monitoring to verify suitability and confirm costs.
6. Full-scale use of storage reservoir.

Work of this nature is already under way in several locations in Alberta. The Heartland Area Redwater Project (HARP), Alberta Saline Aquifer Project (ASAP), Wabamun Area CO_2 Storage Project (WASP) and the Shell Quest projects are all under way. They are in the screening and/or testing phase and progressing to injection testing, which will significantly improve the understanding of direct storage potential in the Fort Saskatchewan and Wabamun areas.

Further study including completion of the Canada CO_2 Storage Atlas is recommended to advance the ability of CCS proponents to screen suitable storage sites.

It is important to support three to five direct storage demonstration projects in the near future – not just one or two. The greater number will allow for statistically more significant results. The highly variable nature of the earth's geology could lead to an unsuccessful result if only a single test is conducted. Such an outcome could set back the acceptability of this technology, unless there were other demonstrations proceeding successfully in parallel.

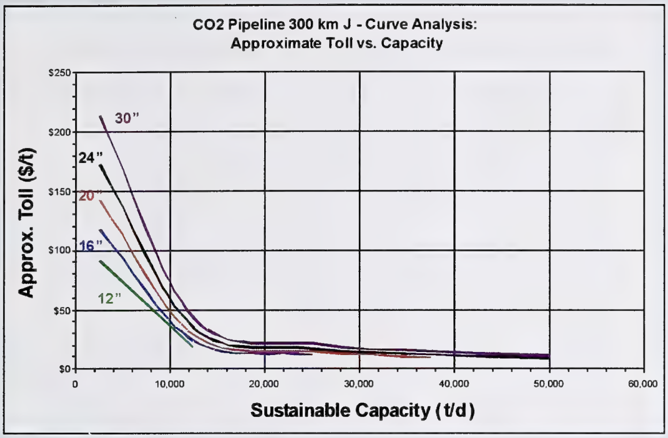
The costs of CO_2 storage in depleted gas reservoirs or saline formations has not been estimated in detail. It is expected that the majority of the costs will be from the initial capital to drill wells, install injection lines and put in place other surface facilities. Over time, the costs of monitoring, measurement and verification (MMV) will grow with expenditures for seismic and other subsurface techniques used to verify that the CO_2 remains in the injection zone.

3.2.4 Infrastructure – CO_2 Pipelines

At distances beyond 50 km, the proven and most cost-effective method to move CO_2 is through high-pressure pipelines. At high pressures, CO_2 exists in a dense phase, which gives it a property similar to liquid water and low pipeline pressure losses. The U.S. has pipelined at high pressure large volumes of CO_2 more than 800 km from the Rocky Mountain regions of Colorado into West Texas since the early 1980s.

A CO_2 purity specification above 95 per cent, which is suitable for EOR use, is appropriate as a pipeline CO_2 specification, as long as the CO_2 is dehydrated to prevent water-based corrosion. In fact, a purity lower than 95 per cent could be suitable for transportation and direct storage of CO_2 that will not be used for EOR, and some capture cost savings could result. The savings from this approach is judged to be modest, and it was not reviewed in detail by the Council. Pipeline costs were estimated assuming CO_2 purity above 95 per cent.

CO_2 Pipeline System Costs



Source: **Canadian Energy Pipeline Association**

The cost of CO_2 transport via pipeline can be easily and accurately estimated with conventional pipeline system analysis. The Council asked the Canadian Energy Pipeline Association (CEPA) to produce an estimate of CO_2 pipeline costs, as shown in the preceding figure. The basis was pipeline costs for 2008 Alberta conditions. Pipeline steel price declines of 40 per cent from July to October 2008 could temper future installed costs by as much as 10 per cent.

Volumes over 5 Mt/year on a 300-km route can achieve costs of less than $20/tonne of CO_2 transported. Volumes of less than 1 Mt/year on lateral routes of 20 km can achieve costs of less than $5/tonne of CO_2 transported.

Discussion has taken place regarding the idea of a CO_2 pipeline network (a coordinated set of interconnected pipelines to optimize the movement of CO_2 from capture points to storage locations), and a review of the benefits and disadvantages of this approach was undertaken. The key benefits include:

- Higher volumes per individual line segment leading to lower costs;
- Reduced proliferation of pipelines with a lower environmental footprint;
- The number of storage sites can be minimized and thus those candidates with the best geotechnical quality can be given priority; and
- An open access pipeline can provide fair space allocation to smaller entities, and multiple EOR markets and supply points provide choice and volume security to participants.

The primary disadvantages of a network approach include:

- The potential for inefficient "planned" development timing with no discipline of the private market or competition between line proponents to drive down costs; and
- A common EOR-quality CO_2 specification may be more than is needed for simple direct storage.

CEPA has provided a series of alternatives that would allow a degree of market responsiveness and discipline while achieving some of the ultimate benefits of a network approach. CEPA does not endorse one particular model as each circumstance depends on the economics. The alternatives are:

- Market Approach

  Pipelines are designed and built as part of an overall project's commercial arrangement and would be built on a dedicated basis or on a network basis as determined by the economics and commercial terms of the project. The latter could take into account any government funding that may be available on an integrated project basis.

  CEPA believes a market approach is applicable where project economics are sufficient to result in commercial agreements between parties. These types of initiatives would be expected, and in fact in most cases intended, to create some pipeline segments that could be applied to a future network. If one or more segments follow similar corridors, then project proponents would normally optimize their own given financial drivers to reach the lowest capital investment.

- Market Backstop

  Incremental pipeline network infrastructure that would otherwise be uneconomic, based upon initial market supply and demand (e.g. incremental diameter) could be constructed with some form of financial backstopping by government. This would support additional supply volumes in the future or would provide a backstop in the event that volumes did not materialize as anticipated.

  A market backstop approach can make sense if some limited level of incremental infrastructure is required for the long term, but it could not be economically justified at early stages of development.

- Market Franchise

  A transportation network that may be required based upon related government policy decisions (e.g. exclusive public funding of oil sands based CCS) and is not economic would be constructed per government policy and fully backstopped. The franchise owner would be selected through competitive bids based on cost and other criteria as appropriate, such as risk and operations considerations.

  The market franchise approach would generally apply where a transportation link is essential based on other public policy decisions, but uneconomic at the time. If government funding is provided, then the benefit to the public must equate to the level of government investment of guarantees.

These alternatives represent mechanisms that provide a blend of private sector discipline coupled with provincial oversight in cases where government action is required in the development of this new industry. The Council agrees with CEPA's views and recommends that the Government of Alberta ensure that initial CO_2 pipelines are designed to facilitate their ultimate incorporation into an efficient provincial network through the use of both market and regulatory mechanisms as required.

4.0 The Business Case for CCS

Alberta, as noted previously, is uniquely positioned in having one of the world's largest hydrocarbon resource bases in close proximity to several potential large point sources of CO_2 capture. The hydrocarbon resource base provides opportunities for significant capacity for CO_2 storage, including the supply of CO_2 for use in EOR. In order to advance the development of EOR opportunities, abundant and affordable CO_2 is required by the EOR industry so that the risk adjusted returns from this new activity are competitive with the other resource development investment options.

There is a strong desire within Alberta to maximize the use of this environmental opportunity, but it can only be done on a large scale within the context of maintaining Alberta's competitive advantage. Alberta's hydrocarbon industry requires capital to continue to grow; impairment of profitability relative to competition for that capital will have a significant impact on Alberta's ability to maintain investment and growth.

Alberta's hydrocarbon industry recognizes that carbon emissions cannot continue to grow. There are threats to industry's ability to market oil sands products and for the continued use of coal as an effective source of electricity in the province. Industry realizes it has a part to play in the global solution to climate change.

To advance CCS in Alberta, finding the right economic balance requires an appreciation of the costs and opportunities to develop a path forward. Should compliance costs for large emitters in Alberta increase beyond the level that is competitive with other jurisdictions, Alberta would be less attractive for investment. As a result, it could experience reduced levels of resource development and fewer value-added investments such as upgrading. These investments have been key drivers for Alberta's economic prosperity. Alberta needs competitive CO_2 emission compliance costs in order to remain internationally competitive. It also needs a program that supports CCS financially, in order to meet the objective of accelerating the widespread adoption of CCS. This is consistent with the vision set out in the *Provincial Energy Strategy* (2008).

4.1 The Financial Gap

CO_2 capture costs greatly exceed the price that EOR operators are able to pay at the present time and for the foreseeable future. Until this difference or gap can be reduced, industry cannot invest in CCS without incurring a loss, or without placing it at a competitive disadvantage.

The Hypothetical Economic Profile chart on page 39 sets out the financial challenge of advancing CCS. It assumes capture costs are in the \$100-to-\$125/tonne range, a level consistent with a potential capture level of 20 to 25 Mt/year as shown in the CO_2 Capture Cost Curve graph in Section 3.1 of this report. Costs could be lower than this level for some projects, and would be higher for others as outlined in Section 3.1. Points to note include:

Costs

- The CO_2 capture costs are split approximately equally between capital costs for the equipment and ongoing operating costs to run the capture process.
- Pipeline costs could be \$25/tonne of CO_2 depending on the location of the capture facility and type of pipeline infrastructure built.
- The total cost of capture and transportation could be \$125/tonne at \$100/tonne capture cost, or as much as \$150/tonne at \$125/tonne capture cost.

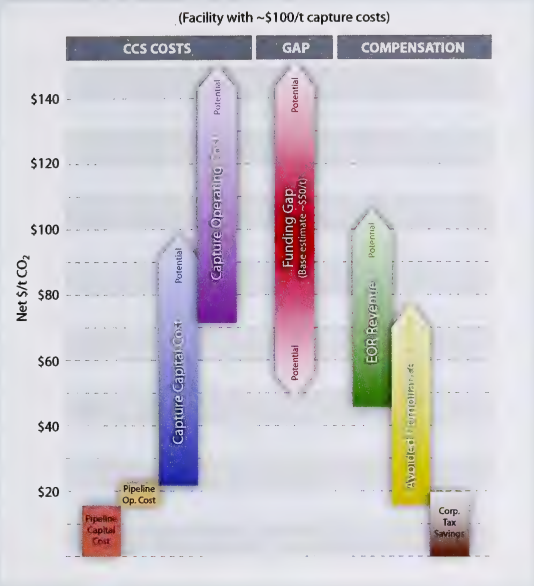
Compensation

- There is the potential for revenue from "selling" the captured CO_2 to EOR firms, but the price for CO_2 and the volume that could be sold are difficult to estimate at present and they depend on CO_2-based EOR being proven commercially successful and as an attractive investment alternative to other types of resource development opportunities. As shown in the chart "CO_2 EOR Storage and Recoverable Oil Potential" in Section 3.2.1 of this report, the level of world oil prices and the price able to be paid by EOR operators for the CO_2 will determine the overall opportunity for EOR production. CO_2 prices between \$0 and \$60/tonne have been assessed with higher CO_2 prices reducing the overall level of EOR that is undertaken. The Hypothetical Economic Profile chart on page 39 assumes a CO_2 price in the range of \$25/tonne.
- There is also the avoided cost of compliance to consider. If CCS is implemented, will it enable a plant to avoid meeting a mandated compliance obligation such as the current \$15/tonne contribution for Specified Gas Emitters, which is in place in Alberta? The future size of this avoided cost of compliance is difficult to predict at present as international, national and provincial frameworks for emission reduction rules continue to evolve. The chart assumes a \$30/tonne avoided cost of compliance.
- The cost of CCS capital investment and ongoing operating costs could lower the profitability of the development firms, and there would be a corresponding reduction in corporate income taxes and potentially royalties, assumed to be in range of \$15/tonne in the chart.

Funding Gap

Given this framework, there is a sizable financial gap that is an impediment to moving CCS forward. Until that gap is addressed, CCS will not move forward in a significant way.

Hypothetical Economic Profile



Source: **Development Council Evaluation**

These costs are based on various studies and what is known today about CCS. Costs can vary widely from one study to the next and are unique to a specific facility. This cost uncertainty is a significant source of risk to companies considering moving forward. Initial projects will inform all stakeholders of the costs involved, and will reduce the risk of the significant uncertainty surrounding the costs – a major hurdle for firms to move forward and implement CCS. The $2-billion CCS fund announced by the Government of Alberta in 2008 will begin to address this issue.

4.2 Opportunities Generated by CCS

The analysis undertaken by the Council suggests there are substantial opportunities that come from the successful implementation of CCS. They include incremental resource development opportunities from EOR, additional value-added processing activities, securing cost-effective power generation from coal-fired power plants, and securing future oil sands development. These opportunities will provide the basis for a sustainable and growing economy, which in turn will increase government revenues and provide a business case to support government investment in CCS.

It is the Council's view that it is in the best interest of Albertans and Canadians to financially support the wide-scale deployment of CCS in order to secure the environmentally responsible development of our world-scale hydrocarbon resources as well as the value-added opportunities that are linked to this development. The Council recommends that Alberta and Canada provide the financial support required for CCS to proceed.

The balance of this section summarizes some of the key considerations for important sectors of the economy. It is followed by a summary of the business case for government support of CCS, suggested principles to advance the adoption of CCS, and an analysis of approaches to supporting CCS.

4.2.1 Enhanced Oil Recovery

As outlined in Section 3.2.1 of this report, there is a range of annual EOR CO_2 demand potential between 12 and 38 Mt/year, with an assumed base case of about 20 Mt/year. This would result in incremental oil production providing substantial financial benefits:

- Assuming oil prices of $75/barrel, about 1.4 billion barrels of incremental oil production could be achieved using existing EOR technology. The potential EOR opportunity would be 2.1 billion barrels as technology is developed for immiscible and heavy oil pools. At oil prices of $75/barrel, the incremental 1.4 billion barrels would provide revenue of $105 billion over the development life of these reserves.

- If oil prices were $100/barrel and technologies were developed for immiscible and heavy oil pools, the incremental production from CO_2 EOR is estimated at approximately three billion barrels, producing $300 billion of incremental revenue.

- Assuming a combined provincial Crown royalty and tax rate range of between 11 and 27 per cent, which depends on oil price and project type, the incremental revenue from EOR has the potential to contribute between $11 to $25 billion (1.4 billion barrels at $75/barrel) and $43 to $81 billion (3.0 billion barrels at $100/barrel) to future provincial balances. Alberta would benefit through increased jobs, taxes, and royalties from the investment to develop and produce these currently unrecoverable resources, and industry would benefit from increased cash flow for investment. The federal government would also benefit from increased tax revenues, and the Canadian economy would be strengthened as the benefits of this investment and profitability supported incremental growth.

Using CO_2 to enhance oil recovery is the one commercial aspect of the whole CCS chain. While there are several pilot projects, the use of CO_2 for EOR is not a widely practised technology in Alberta, mainly due to the unavailability of low-cost CO_2 and the need to develop the technical expertise to conduct CO_2 EOR projects.

For the initial stages of CCS development in Alberta, there is potential that EOR operators would be able to take most, if not all, of the available CO_2 supply if economic conditions were favourable. In this environment, the supply/demand dynamic would ensure that a reasonable price is paid by EOR companies for CO_2, thereby reducing the CCS financial gap and the required government support to reduce that gap. The market for CO_2 will be fragile due to the large capital investments required and the substantial volumes of CO_2 that will be captured with each new plant. During the early stages of CCS development, each new plant that begins to capture CO_2 will add a significant volume of CO_2 to the market, relative to the size of the existing market.

It is also possible that over the longer term, capture levels may exceed demand by EOR firms thereby requiring other storage options. The Council recommends that

Alberta work with industry to ensure that a fair and balanced price for CO_2 is maintained so as to maximize the use of CO_2 for EOR while contributing to reducing the overall cost gap of implementing CCS.

4.2.2 Oil Sands Resource Development

The Council also considered the benefits of oil sands development. Typical integrated oil sands projects require billions of dollars of investment, and provide substantial revenues for decades. Governments are major beneficiaries of the wealth generated by these projects, receiving a significant percentage of the available cash flows as royalties and taxes. It is apparent from recent market turmoil that oil sands development is vulnerable due to its capital intensity and relatively high ongoing operating costs. In order for developers to add CCS to their projects, there has to be an appropriate level of financial support for this incremental spending. If a framework is put in place to support CCS effectively as a means to achieve long-term CO_2 compliance, there are likely to be more oil sands projects developed, resulting in billions of dollars of additional investment benefiting our economy, government balances, and citizens.

4.2.3 Electricity Sector Considerations

Alberta's coal resources are more than twice as large as its world-scale oil sands resources. Putting in place the framework for CCS to be adopted for coal-fired power plants will help to keep Alberta's electricity prices competitive, reducing the cost to consumers and enhancing economic development in the province.

The issues related to CCS deployment in the electricity sector are similar in most respects to other sectors, but there are some important differences. These differences relate primarily to cost impacts and deployment potential.

Fossil-fired electricity generation is the largest single CO_2 emission source in the province at approximately 54 Mt/year, representing about 10,000 megawatts (MW) of installed capacity. The majority is from large coal-fired power plants providing base load power to the province's grid.

Alberta's electricity sector has certain characteristics that play a role in how CCS will be implemented, including:

- Large central facilities with long lives and therefore slow capital stock turnover;
- A relatively modest but steady domestic growth profile given the relatively low interconnectivity of the Alberta electricity grid with other regions;
- Access to tremendous reserves of low-sulphur sub-bituminous coal;
- Large, discreet emissions sources; and
- A competitive, deregulated electricity market.

Some of these characteristics are advantageous to CCS. Large sources mean that sizeable volumes of CO_2 are available at each facility, conducive to large-scale CCS installation in the 1-Mt-or-greater range. The potential longevity of these facilities may also allow for improved economics associated with CCS incremental investment.

In terms of the coal reserves, CCS will play a slightly different dynamic than it will for oil sands reserves. The greatest benefit of CCS for the electricity sector will be to allow the continued utilization of coal to produce power in an environmentally acceptable manner, thus keeping Alberta's electricity prices stable, dependable and competitively priced. As electricity is a fundamental input to most other industrial activity, CCS applied to the electricity sector has the potential to benefit all consumers.

The deregulated nature of the Alberta electricity market will create challenges for those companies that lead the early deployment of CCS projects. Recovering incremental capital and operating investment while being able to competitively bid into the electricity market will not be possible with the current deregulated bidding structure. Ultimately, the cost of CCS can and should be reflected in consumer prices, with the understanding that in the long run CCS will keep Alberta's electricity prices low, and will support a competitive industry. Given the complexities of introducing the significant cost of CCS into the deregulated electricity market in Alberta, the Council recommends that the Alberta Department of Energy review potential mechanisms that would not place early CCS implementers at a competitive disadvantage.

4.2.4 Value-Added Processing and Manufacturing

The *Provincial Energy Strategy* (2008) sees the advancement of value-added activities, such as gasification to unlock low-value resources including bitumen bi-products and coal. These technologies can most effectively move forward with CCS, as they are carbon-intensive, but also of significant value. Gasification with CCS creates the opportunity to reduce domestic natural gas use, making more available for export and creating wealth for Albertans.

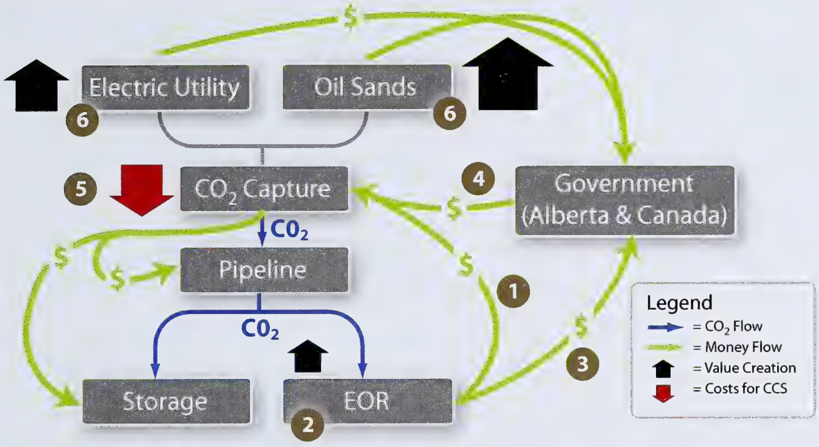
The *Provincial Energy Strategy* also seeks to ensure that a high level of oil sands upgrading occurs within the province.

Alberta continues to develop a range of other value-added industries, some of which build on the unique resource base that the province possesses. The ongoing development of value-added industries is key to maintaining a sound and diversified economy and providing tax revenue to governments.

4.3 The Business Case for Government Investment in CCS

The following chart illustrates the linkages between wealth creation and CCS cost management.

BUSINESS CASE FOR GOVERNMENT INVESTMENT IN CCS



Implications:

1 - EOR CO_2 purchase price needs to balance creating a robust EOR market and providing value to capture
2 - This will directly impact how robust EOR market is
3 - More robust EOR will impact how much benefit government receives
4 - Government can cycle value back to support capture
5 - Combination of revenue from EOR and government support will determine economic cost of capture
6 - Cost of CCS will impact overall corporate investment decisions in electricity and oil sands affecting economic impact of both industries

Source: **Development Council Evaluation**

The chart outlines the following key points:

- Coal-fired electricity results in competitive electricity prices for Alberta's economy. Coal-fired electric utilities pay corporate income taxes and coal royalties to the Government of Alberta.
- Oil sands projects are major value creating investments and generate ongoing royalties and taxes that flow to both the federal and provincial government.
- CO_2 capture via CCS is an economic cost and requires financial support from governments and revenues from EOR to be a financially feasible alternative to other compliance approaches.
- CCS will provide development opportunities for pipeline companies, storage companies and EOR companies. Pipeline and storage activities will require financial backstopping from capture firms or governments and will generate employment and taxes for Alberta.
- EOR firms have the potential to create significant incremental value from the development of currently unrecoverable light and heavy oil resources. A portion of this value will flow to governments through royalties and taxes, and it can also flow to CO_2 capture firms as a price for CO_2, which will help offset a portion of the costs of capture.

The positive flows to governments from CO_2 EOR, incremental oil sands and coal resource development, and other value-added activities provide an ongoing revenue source to governments in addition to the basis for a sustainable and growing economy. As noted above, the Council believes it is in the interest of Albertans and Canadians that both the federal and provincial governments use a portion of the wealth created from these activities to support the widespread adoption of CCS.

4.4 Guiding Principles to Advance Widespread Adoption of CCS

The Council considered a number of principles that could be used by governments as they determine the approaches that will best meet their objectives. The Council recommends that Alberta adopt these or similar principles to guide the development of CCS within the province:

- **Avoid carbon "lock-in" – provide clear early signals.** Oil sands, coal and other major manufacturing and processing projects take considerable time and expend considerable cost to engineer prior to approval for construction. In addition, there are often significant regulatory review processes. In order for new projects to incorporate CCS from the design stage, clear and strong signals about the medium-term support program for CCS will be required in 2009; government needs to be clear about GHG mitigation policy. In the absence of this, it is likely that more projects will be built without CCS, which will make it more difficult and expensive to deal with CCS in the future.

- **Market-based approach where possible.** Incenting the development of CCS in Alberta could be done with greater or lesser degrees of direct government intervention including roles such as market maker, infrastructure owner, project approver and auditor. Where possible, using market-based mechanisms to enable private sector players to bring their ingenuity to the task of CCS may lead to the greatest long-run benefits.

- **Policy continuity.** It is expected that in the near term several firms in Alberta will have begun CCS projects under the full project proposal (FPP) process, meeting one of Alberta's initial CCS objectives. The support provided to these projects should reward early initiative and risk taking. However, it is also important to provide sufficient support for other projects that come forward over the medium term to enable them to proceed.

- **Administratively feasible/deliverable.** The mechanisms chosen to deliver support for CCS should be designed in a manner that provides a high level of assurance that their objectives can be met in a timely and clear fashion. Designing programs that have difficult to achieve goals, or failing to resource the program delivery teams adequately with skilled staff, could lead to delays or a loss in confidence on the part of industry.

- **Appropriate risk sharing between government and industry.** Industry has a track record of managing certain types of risks – such as those for design, construction and financing. Government should seek to ensure that industry has an incentive to properly manage the risks that it can. Government should also retain the risks that are most appropriate for it to manage, such as evolving compliance burden risk.

- **Ability to accommodate national and international climate change frameworks as they evolve – policy robustness.** Over the past several years there have been a number of changes in provincial, national and international approaches to climate change, and it is likely that there will be continuing evolution in the years to come. The CCS program that Alberta designs should contemplate the range of possible approaches that could be developed and provide a mechanism to accommodate these changes while maintaining the original program objectives.

- **Works for all key sectors in Alberta.** The CCS program that Alberta adopts should be designed to work across industry segments and technologies to achieve the appropriate level of CCS deployment at an acceptable cost.

- **Price discovery where possible.** Alberta's initial $2-billion CCS fund will provide additional information on the costs of a limited number of CCS projects over the coming years. This database will still be small relative to the scope of approaches that might be taken, so it would benefit Alberta if the medium term CCS support program contained an element of price discovery or reporting.

4.5 Approaches to Supporting CCS

Following the Council's recommendation that both the federal and provincial governments provide the required support to advance the widespread adoption of CCS, alternative approaches to providing financial support were explored by the Council. These are outlined below, together with the Council's views on their merits:

- **Pay for Results:** This approach is based on delivery of financial support to CCS through a standardized dollar-per-tonne-captured payment at a level that provides sufficient support that private sector developers would invest in CCS projects. This is the Council's recommended approach for CCS.

  - Under this structure, capital costs, operating costs, technology and operational risks would be borne by the CCS developer, creating strong incentives for risk management as well as incentives for cost optimization.

  - Financial support could be adjusted to account for alternative compliance costs as they evolve, or from the expected revenues that could be received from sales of CO_2 to EOR firms.

  - It might also be possible to set the level of the financial support payment differently for certain industries or different technologies if there was sufficient information available on which to confidently base such a distinction. The most cost-effective CCS projects in each segment would be most likely to be constructed under a standardized payment-per-tonne support mechanism.

  - The support payments could be delivered as part of a long-term agreement based on measurable CO_2 captured to provide confidence in the stability of the support provided as private sector investment decisions are being evaluated. Higher support payments to offset first mover disadvantages for projects that are developed early and lesser payments for those that come later, when the capital, technology and regulatory risks are reduced, may incent early action.

- Payments would be set at a level adequate to achieve an expectation of widespread implementation of CCS by industry for most new projects. There would need to be clear communication of the structure of the system and certainty about the delivery mechanism to incent developers to make CCS part of the design of new projects despite the added costs and risks.

- Payments would be available to all CCS projects, since widespread adoption of CCS would be required in order for Alberta to meet its objective of reducing the overall level of CO_2 emissions in the province. There will also be a need for CCS retrofits of many existing plants. A high level of CCS uptake for new projects would be a measure of success of the program and would result in incremental government revenues from the new projects and from the EOR undertaken with the CO_2.

- The CCS support payments should be structured to ensure tax efficiency for industry. For example, it would be inappropriate for payments from Alberta to CCS developers to result in increased federal tax revenues when both governments share a common objective of advancing CCS.

- CCS developers would be responsible for the development of pipelines and for negotiation of arrangements with EOR developers or storage site developers. There may be a role for ongoing dialog between industry and government to identify and capture synergies to reduce overall systems costs in these areas.

- The Pay-for-Results approach is likely to be administratively feasible as the level of the support payment would be set up front, a standard agreement structure could be developed, and captured CO_2 volumes could be verified. As there is a potential for multiple types of projects occurring over similar time-frames, administrative feasibility is a key success factor for program design.

An extensive series of other mechanisms were considered; all have positive and negative features. Although none of these approaches are as favoured as the Pay-for-Results alternative, they could be studied further and considered suitable depending on how national and international GHG compliance evolves, or as tactical approaches to use as part of a CCS support strategy.

- **Customized CCS Support:** This approach would seek to target the support payment for each project to the exact level required in order for the project to be approved by the developer. It would set payment levels uniquely for each project, likely through a RFP or reverse auction mechanism.

  - This approach has the potential to lower the cost of the payments to support CCS if there is a competitive and effective process for CCS developers to compete for funding.

  - The approach relies upon a sound understanding of the costs and project opportunities for CCS, so that the reverse auction or the FPP process can be effectively managed. A reverse auction is a competitive process where projects are accepted based solely on the basis of the minimization of the support costs requested by the developer.

- As there may be a need for most, if not all, new projects to include CCS to meet Alberta's objectives, this process may lack the competition that is evident in the Government of Alberta's initial $2-billion CCS fund process. If all potential CCS developers know that Alberta desires these projects to proceed, the incentive to reduce costs may be reduced.

- This approach may be more administratively difficult; establishing individual payments levels and agreements and running multiple rounds of RFPs is likely to be complex.

- The level of support available would be less certain to most developers as they may not understand who is competing for funding or the cost structures of these competitors. Increased uncertainty about the ability to secure acceptable support on a timeline that coincides with development plans may lead to a higher number of projects that are unwilling to take the risk of CCS.

- There may be a potential for "bidding up" the required level of support – determining what the project prior to yours was able to negotiate, and then seeking better terms than that. This type of rent-seeking behaviour could delay the implementation timeline for CCS.

• **CCS Fund:** This approach would be delivered through an increased compliance burden on emitters in Alberta with the additional revenue generated used to fund specific CCS projects or to pay a dollar-per-tonne credit to encourage CCS.

  - This approach could build upon the Specified Gas Emitters program with an incremental charge for CCS support. Funds could be distributed to CCS projects under either a Pay-for-Results approach or a Customized CCS Support approach, and would have the benefits and challenges of these approaches.

  - The level of the increase compliance obligation would have to be set to adequately meet the desired level of CCS development; this would be challenging to do in advance, given the limited level of information about CCS costs and project timing.

  - The increased compliance burden, if it is uncompetitive, would likely lead to reduced levels of investment in resource development and value-added processing, which could result in lower overall economic activity and reduced government revenues. Compliance costs that are above those of competitive jurisdictions may not meet the objectives of the *Provincial Energy Strategy* (2008).

• **Tax and Royalty Measures:** This approach would be delivered through adjustments to tax and royalty systems to improve the after-tax return of projects that include CCS. The Council recognized that there may be a role for the use of these mechanisms as a means of implementing the overall approach to CCS.

  - This is a support delivery mechanism rather than a comprehensive approach to program design.

  - It is unlikely that the magnitude of tax or royalty measures on their own could have sufficient impact to materially change the implementation schedule for CCS projects. These measures may be one means of delivering part of the required support, for example as part of a Pay-for-Results approach, however

further analysis of the different tax situations of potential CCS sponsors would be required to determine the level of impact that could be expected by particular measures.

- **Multiple Credits:** This approach relies on providing disproportionate credit to CCS developers relative to other forms of CO_2 abatement under a regulatory scheme.
    - ➢ This approach requires that there is a pool of tradable credits or another pricing mechanism for CO_2 that is in place, stable and predictable so that CCS sponsors know that they can rely on the value of these credits for many years into the future as CCS projects have decades-long operating lives.
    - ➢ This approach typically shifts a portion of the incidence of the cost of CCS to other CO_2 emitters within the jurisdiction. If additional free credits are provided to the CCS projects, the value of credits is either diluted or the costs are inflated, if a portion of the credits that would have been available are removed to provide them to the CCS projects at no cost.
    - ➢ It does not appear that there is sufficient development of compliance mechanisms in Alberta or Canada at present to enable a Multiple Credit approach to provide a strong enough signal that CCS projects will be undertaken.
- **CCS Cost Pass Through:** This approach would seek to have the incidence of incremental CCS costs borne by consumers where possible. Attempting to pass CCS costs to electricity consumers via increased electricity prices is not likely to be effective in the near term due to the generation mix and electricity market structure in Alberta. The Council believes this approach merits further consideration in the electricity sector.
    - ➢ A direct charge on consumers to fund the CCS undertaken by the electricity sector could be considered.
    - ➢ It is not possible to pass the costs of CCS to consumers of oil or natural gas as these are internationally competitive markets and Alberta producers are price takers who lack market power to influence the prices that are received for their production.

The following alternative to stimulate EOR demand for CO_2 was considered:

- **CCS Agency:** This approach would require Alberta to set up an agency to act as purchaser of captured CO_2, shipper of CO_2 on new CO_2 pipelines, and seller of CO_2 to EOR companies.
    - ➢ While this approach appears to offer the potential to capture value from EOR by maximizing the CO_2 price charged to specific EOR projects, there would be implementation challenges and costs, the potential for an increased level of uncertainty, and the potential to delay implementation of CCS due to the controlled market.
    - ➢ This approach may not be administratively feasible.

- ➢ There is a potential for a perceived lack of fairness as the agency "picks winners" in order to fulfill its mandate.

- Further consideration regarding CO_2 price management should be undertaken in order to find a balanced approach to share the value of CO_2 between EOR companies, capture firms and governments.

5.0 Regulatory and Governance Considerations for CCS

5.1 Project Application Process and Project Operation[9]

As the primary regulator for energy development in Alberta, the Energy Resources Conservation Board (ERCB) regulates the transport, injection and operation of CCS development. The ERCB has approximately 20 years of history dealing with small-scale CO_2 injection and has a regulatory framework in place to address the public safety, environmental protection and resource conservation aspects of small and larger scale CCS development.

The ERCB has made considerable progress in preparing for CCS applications. The Council recommends that the ERCB ensure that it has appropriate resources and processes to review CCS applications in a timely manner. This will ensure that the ERCB can provide timely examination of applications and the "learning-by-doing" can happen expeditiously.

The Council acknowledges the decision of the Government of Alberta to incorporate mandatory capture and storage requirements into facilities, at some point in the future. The learning by doing approach to CCS regulations and, more broadly, around the practical realities of implementing CCS, should apply to capture and storage requirements, with initial regulatory requirements requiring facilities to be "CCS-ready." The core focus of this report has been on identifying which activities could move CCS forward. There remains a clear and significant gap overall in implementing this critical technology. As such, it is recommended that the development of requirements for "CCS-ready" be further assessed based on the results and knowledge garnered from the first round of projects under the $2-billion CCS fund. Based on this timing, "CCS-ready" requirements should be considered in the 2010 to 2015 timeframe, with

[9] Input from the ERCB: The ERCB considers CO_2 an acid gas when injected into a subsurface environment and applies its acid gas disposal regulations to CCS development. Regular review of regulations occurs to ensure direction to industry is current and reflects the latest technical developments. As applications for CCS development occur the ERCB will enhance regulations as required based on increased knowledge and experience.

The ERCB regulatory approach to CCS development is not consolidated into a single directive but rather occurs over multiple regulations based on aspects such as the subsurface environment, land infrastructure, public consultation and well construction (Directive 65, Directive 56 and Directive 51). In addition to published regulatory requirements the ERCB can place additional unique "conditions" on any approved CCS development. Unique conditions are used to ensure that specific technical differences from one development and another are taken into account.

Industry participants involved in CCS to date have demonstrated a good understanding of the technical requirements for CCS development and associated regulations. In the past several years increased interest has occurred from operators less familiar with CCS development. As a result the ERCB will be releasing an application guidance document in Spring 2009. This ERCB document will provide industry-consolidated guidance on the main ERCB regulations and directives that should be considered when submitting an application for CCS development. Although the document is focused on industry use others interested in CCS development will find it beneficial to understanding the comprehensive CCS regulations in Alberta.

mandatory requirements based on further experience over the 2015 to 2020 timeframes. However, specific individual activities may be considered in parallel to this. Steps are already being taking to incorporate this requirement into specific activities within the province through Alberta Environment's Policy 1a (http://environment.alberta.ca/documents/OSEMD_Approvals_Program_Policy.pdf). This policy requires that commercial scale in-situ facilities that propose to directly burn non-gaseous fossil fuels such as bitumen, petroleum coke, or asphaltenes for bitumen production, will be considered for approval only if the facilities are CCS-ready. This will serve to further complement the knowledge for developing a broader provincial policy.

5.2 Storage Access – Tenure Issues

Access to pore space to dispose of CO_2 is a critical issue for CCS development. Clarity on pore space and disposition rights ownership has been identified by the Canada/Alberta ecoENERGY Carbon Capture and Storage Task Force as an important step to move the first CCS projects forward.[10]

5.2.1 Property

Legislation in Alberta has addressed ownership of storage rights in subsurface reservoirs. Section 57(1) and (2) of the *Mines and Minerals Act* confirms that the owner of title to petroleum and natural gas in an underground formation owns the storage rights in that formation, and that the owner of title to a mineral that is removed to create a subsurface cavern owns the storage rights in that cavern. Those provisions confirm ownership of storage rights not only in relation to Crown-owned petroleum, natural gas and minerals, but also in relation to freehold-owned petroleum, natural gas and other minerals.

Section 9(a)(iii) of the *Mines and Minerals Act* allows for the entering into of Crown agreements for "the storage of substances in subsurface reservoirs." Section 102 of the *Mines and Minerals Act* allows the Crown to enter into unit agreements that provide for the "use of the subsurface reservoir for the purposes of storage of fluid mineral substances."

Current provisions of the legislation governing ownership of storage rights relate mainly to oil and gas production and related activities, but it remains unclear as to whether these rights extend to permanent disposal. Consequently, the Council recommends that legislation be enacted to provide clarity with respect to disposal rights.

For saline formations, Section 3(2) of the *Water Act* vests in the Crown, the property in and the right to divert and use water in Alberta. Consequently permission to dispose of CO_2 in saline formations might be granted pursuant to the Act. Permitting such activities, and in particular, doing so for the purposes of reducing CO_2 that would

[11] Immediate Action #2 – Authorities responsible for oil and gas regulation should provide regulatory clarity to move the first CCS projects forward by: quickly confirming legislation and regulation related to pore-space ownership and disposition rights; clearly articulating the terms for the transfer of long-term liability from industry to government; and increasing the transparency of regulatory processes.

otherwise go to the atmosphere, reflects a new area of environmental management for saline formations.[11] This effort needs to be considered in the context of water and other environmental management interests. To most effectively deal with disposal of CO_2 in support of CCS, including disposal in saline formations governed by the *Water Act*, the Council recommends:

1. A transparent process involving the departments of Energy and Environment and the ERCB be developed for administration of processes to support CO_2 disposal;

2. Legislation be enacted to clarify the ownership of disposal rights in saline formations, to provide for the granting of the use of those disposal rights to others by way of agreement, and to provide for the circumstances in which those rights supersede other rights (e.g., storage rights) in the same formation; and

3. The departments of Energy and Environment, including the ERCB, jointly issue information on the process and procedures around disposal rights and requirements.

5.2.2 Disposition Process

The Alberta Department of Energy has a well-established tenure rights issuance process for petroleum and natural gas, oil sands and other minerals rights. It is recommended that with some modification similar processes be used for the issuance of disposal rights for CO_2.

While a regulation-based process for issuing disposal rights would provide the greatest certainty, given the early stage of CCS, it would be more appropriate to use Crown Agreements rather than disposal regulations as experience during the initial years will serve to inform drafting of regulations if the volume of tenure agreements warrants a more structured approach in the future.

Mineral rights are allocated in Alberta by a process of public auction, with rights going to the highest bidder. This process would not be appropriate for CO_2 disposal rights for a number of reasons, including the uncertainty around the value of those rights as well as the expectation that, at least initially, there will not be a significant number of requests for these rights. The Council recommends, however, that the process for acquiring CO_2 disposal rights be open and transparent and that access to disposal rights reflect the capacity of storage space needed, to avoid speculation in this market. To provide clarity to industry on how to access rights to dispose of CO_2, the Council recommends that the Alberta Department of Energy develop and publish specific guidelines on this process as soon as possible.

[11] Note that the Government of Alberta already has a regulatory system in place and experience associated with injection of industrial fluids while ensuring groundwater protection.

5.3 Long-Term Liability

There is extensive experience among government and industry in assessing, approving and managing the full project cycle for activities involving underground injection, disposal and storage of a variety of materials, including CO_2. This experience, which is supported by an existing regulatory framework, forms a solid foundation for providing assurances around the safe and reliable storage of CO_2. There may be a need in the short term to consider risk profiling of opportune areas for CCS from the perspective of longer term human and environmental impacts.

With a focus on GHG mitigation and given the potential scale of CO_2 storage, there is a shared appreciation among government, industry, and other key stakeholders that a coherent management framework that appropriately considers medium- and long term storage aspects is required. “Long-term” in this context refers to hundreds to thousands of years.

Alberta’s existing regulatory system covers liability aspects around CO_2 storage during the project life, including decommissioning. The key gap that has been identified, both in the provincial context, and as a broader issue for advancing CCS globally, is the long-term liability framework once projects have been appropriately decommissioned.

The establishment of such a framework requires distinguishing the project life, which includes site selection, permit application, commissioning, operation and decommissioning, from the post-closure period. Further, while there are key attributes that should apply to the overall management system, the following are core principles should serve as a guide from the proposed long-term management framework:

- Minimize exposure to health, environment and financial risks for operators and governments;
- Support sustainable development;
- Clarity of rules and reasonableness of expectations over the long term;
- Precautionary approaches should be taken in absence of perfect information;
- Continuous system improvement;
- Data rigor and transparency;
- Appropriate administrative costs; and
- Those harmed by an incident should receive appropriate compensation.

Recognizing the range of potential liability models in existence and being considered, and with further consideration of the existing liability mechanisms in Alberta for the project life, the following outlines a recommended long-term liability framework for the province. This framework represents a starting point to build on through practical experience, recognizing that CCS will most likely be implemented in stages, thus allowing time for policy evolution and continuous improvement.

This framework reflects a sharing of the risk between government and industry to support the development of this technology If industry operates as expected and the project performs as has been agreed, industry's long-term liabilities will transfer to the government.

5.3.1 Recommended Long-Term CO_2 Management Policy Framework

5.3.1.1 Project Life Requirements

The term "project life requirements" includes elements during the project life and also includes requirements for the purpose of managing the long-term liability of CO_2 post-closure.

The consideration of the longer-term fate of CO_2 would be incorporated into each of the key project life steps. Many of these are already in place, or being considered in the process enhancements currently under way. Project approval would be contingent upon having these elements in place to the satisfaction of the regulator. The steps and potential elements could include:

Site Selection and Characterization: A detailed assessment of the underlying geology and land features such as abandoned wells will help develop a longer-term risk profile. This would support a robust stakeholder engagement plan reflecting the key elements of the site characterization that cover the range of potential liability aspects.

Application and Permitting: A proposed decommissioning plan that considers longer term risks and remediation actions. Included in this plan should be the setting of triggers/thresholds for monitoring during the project of areas that produce longer term impacts, have specific fate expectation performance criteria, and have in place mitigation strategies based upon risk profiles.

Operations: Monitoring of the fate of the injected CO_2 and comparison with the predictions in the site selection, and application and permitting phases.

Decommissioning: A continued initial monitoring period of 10 years with consideration of a longer-time period, determined up-front and over the project life and based on site conditions. Also, an assessment of project conditions against identified performance criteria such as pressure levels and per cent of CO_2 dissolved into formations.

Post-Closure: A decommissioning plan being demonstrated to be complete to the satisfaction of the regulator.

[13] Ten years is a starting point for the first round of projects that will have a strong emphasis on monitoring and measurement. Further considerations will be given to an appropriate duration period based on evolving knowledge around the fate of CO_2 – work being undertaking by current and planned pilots and other experiences will inform the appropriateness of this duration period.

5.3.1.2 Post-Closure Requirements

Industry liability will be extinguished after a decision by the regulator that the project meets all expectations during decommissioning. With this, consideration then needs to be given to the liability points associated with the post-closure phase including injection and monitoring wells, CO_2 plume, monitoring, remediation and damages to third party. This will help assess areas where it will be reasonable and appropriate for liability to be transferred to a long-term management program.

Injection and Monitoring Wells: An injection well used for initial start-up, operation and/or decommissioning, is selected for use in the MMV program for assessing the long-term fate of CO_2 after the closure phase.

CO_2 Plume: If the CO_2 plume behaves as expected during decommissioning phase and with consideration of project conditions against identified performance criteria, this element would be satisfied for closure. It would subsequently be transferred to government.

Monitoring Activity: Additional monitoring wells for assessing the long-term fate of stored CO_2.

CO_2 Leak: For any aspects of the projects where government takes on the liability post-closure (e.g. monitoring wells), there is a further liability associated with these elements pertaining to remediation in case of CO_2 leakage, and for damages to third party. The Government of Alberta may need to assume this liability in the long run.

The Council recommends that government incorporate this proposed framework and legislation (enhancements to existing legislation or new stand-alone dedicated legislation if appropriate) to ensure clarity of expectations and assurances around formally addressing identified risks.

The Council recommends that government acknowledge, by way of legislation, that it will accept, after an appropriate term, the long-term liability related to the disposal of CO_2. Risks to the environment, human harm, resource recovery and other potential exposures associated with these liability points and the risks that are extinguished for industry would be covered by this policy.

5.3.1.3 Monitoring, Measurement and Verification Program

A formal MMV program would be created as part of the management framework to support the requirements identified in key project life steps, and support the management of the risks identified in the post-closure phase.

5.3.1.4 Longer-Term Management Framework Costs

The management framework will involve a series of costs for all key parties. While there may be government and other sources of funding, project proponents may also be expected to cover some of the costs. Although other areas may be identified, the key potential cost areas associated with addressing the post-closure liabilities, and a potential approach for payment, including:

Managing Incidences – Fund established with payments from the project proponent at an established 50 cents/tonne of CO_2 injected.[13]

MMV - Program funded through payments from the project proponent at an established 50 cents/tonne of CO_2 injected.[14]

The U.S. has pipelined at high pressure large volumes of CO_2 over 800 kilometres from the Rocky Mountain regions of Colorado into West Texas since the early 1980s.

[13] This is the starting point for early projects. A future rate will need to be set with consideration of the range of potential risks and impacts, while also recognizing that a cost gap for implementing CCS already exists. It is expected that the rate will be adjusted over time with appropriate notice to industry and based on practical experience. Variations in rate schedules would also be considered (e.g., block rates).

[14] This is the starting point for early projects. A future rate will need to be set based on the structure of the to-be-created MMV program, also recognizing that a cost gap for implementing CCS already exists. It is expected that the rate will be adjusted over time with appropriate notice to industry and based on practical experience. Variations in rate schedules would also be considered (e.g., block rates).

5.4 CCS Governance Options

The Council recognizes that some form of governance for CCS will be necessary to ensure that the longer term climate change goals and technology deployment objectives are achieved. The specific governance model that is ultimately selected by government should be established based upon on a set of key principles.

Governance should include a cooperative public and private sector collaboration to actively manage and accelerate the development of the capture, transportation, EOR, and direct storage components of a CCS system while maximizing economic and environmental efficiencies through effective policy development and delineation of risk and investment commitments by key stakeholders.

Short-term needs for a new governance structure would focus on the coordination and management of the first wave of demonstration projects as well as public education and communications.

CCS Governance Principles

Strong Leadership to Maintain Momentum - leadership provincially, nationally and internationally in helping define policy options, communicating with stakeholders/ public, and coordinating with CCS implementer.

Authority - ensures that the first and second phase demonstration projects are completed.

Accountable - to ensure the Council's CCS blueprint gets delivered over the many decades that this will take.

A Long-Term View - that considers not just the immediate phase of demonstration projects but a governance structure that will enable steady progress towards the longer-term (2020 and 2050) goals.

Evolved and Phased - approach to governance that would allow for acceleration or deceleration as future needs dictate, while sustaining the momentum in the short term.

A Collaborative Partnership - to allow for continued policy and financial discussions and implementation coordination.

Stakeholder and Public Engagement - to ensure ongoing dialog with affected Albertans.

Adequate Resources – to ensure a focused and sustained effort is maintained.

Short-term needs (one to five years)

- Sustain the CCS development momentum.
- Champion and be accountable for implementation of the Alberta CCS blueprint.
- Development of a detailed business plan based on the Council's recommendations.
- Forum for industry and government to dialog – in particular, to institutionalize knowledge garnered from the first phase of demonstration projects.
- R&D coordination especially with universities, the Alberta Research Council and others.
- Coordination and nurturing of new demonstration projects.
- Coordination of fine-tuning to site-specific regulations such as ERCB, tenure and liability.
- A "one window" voice on input to federal/provincial CCS-relevant climate policy.
- Linkage to national and international CCS initiatives.
- Public education and outreach on CCS.
- Foster CCS capabilities and human resource development in Canadian industry, government, and non-government organizations.
- Assess and monitor the application of CCS "cost gap" policies and incentives as conditions change.

Medium-term needs would increasingly focus on ensuring that the second wave of projects comes to fruition.

Medium-term needs (five to fifteen years)

- R&D coordination to continue to bring capture costs down.
- Assess the merits of market options (e.g., "waste utility" to buy and dispose of CO_2).
- Linkages and challenges for CCS in evolving cap-and-trade carbon markets.
- Input to federal/provincial climate change policy.
- Pipeline and storage infrastructure coordination and management.
- Project management for Government of Alberta funded projects.
- Assessing ongoing need for "gap support" mechanisms.
- Linkage to national and international CCS initiatives.

In the longer term, it is expected that market forces would drive CCS development. CCS technology should be “off the shelf” and self-sustaining by this time. Clear, consistent and CCS supportive policy from government will continue to be important. At this time, there should also be significant progress towards an integrated CO_2 pipeline within the province.

CCS Governance Options

Authority

- “AOSTRA-like” (public/private partnership), industry linkages, with a longer term mandate to implement CCS in Alberta (10+ years)
- Full budget and accountability by legislation - substantial funding to invest in more demos.

Government Branch/Secretariat

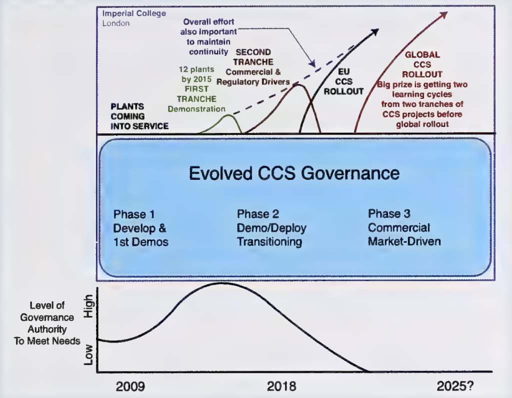
- Establish a dedicated CCS branch or secretariat within government with appropriate resources – perhaps modeled around the Oilsands Sustainable Development Secretariat
- Establish a standing industry advisory group to provide business advice on CCS.
- Establish a standing stakeholder advisory body to provide strategic, R&D and public advice.

Two major tradeoffs are apparent when considering these options:

- Degree to which government needs to retain control; and
- Level of authority to act.

CCS technology development is of considerable interest to several ministries within the Government of Alberta and the governance model selected will undoubtedly facilitate this broad interest.

A phased approach to CCS coordination & management



Source: **Dr. Jon Gibbins, Imperial College London and Alberta CCS Development Council**

Ideally, governance should be in step with the technology development needs at a particular time. Governance should also support a "learn-as-we-go" approach. The preceding chart suggests that the level of authority of a governance body should ramp up prior to a second phase of demonstration projects. A strong governance structure prior to a second phase of demonstration projects would help to maintain the momentum of CCS project developments

The chart also suggests that once the second phase of demonstration projects is completed, CCS technology should be well on its way to widespread adoption. In addition, the broader vision of developing an integrated CCS system in the province, linked by CO_2 pipeline network, should also be well on its way. At this point, a CCS governance structure would no longer be necessary and market forces would prevail.

The Council recommends that government develop a governance model for CCS that will incorporate the CCS Governance Principles in order to maximize the potential for CCS in Alberta.

5.5 Safety Considerations for CCS

Processing, transportation and storage of CO_2 has been accomplished safely in Canada and the U.S. in a number of settings.

One of the best examples close to Alberta is the Weyburn CO_2 miscible flood project in Saskatchewan. CO_2 is transported from a synthetic fuels processing facility in North Dakota through a 320-km pipeline to a partially depleted oil reservoir in southeast Saskatchewan. Over 10 million tonnes of CO_2 have been injected into the reservoir since 2000.

An eight-year joint research project was initiated in conjunction with the facility to monitor the behaviour of the CO_2 and support development of the framework necessary to encourage implementation of CO_2 geological storage. Project partners included the International Energy Agency, Natural Resources Canada, the U.S. Department of Energy, Saskatchewan Industry and Resources, the Alberta Energy Research Institute and a number of industry partners. Reports to date have concluded that geological storage is both safe and reliable. More than 20 research organizations, including several from Alberta, have been directly involved in the project.

The design and operation of CO_2 pipelines and injection facilities is also well understood given experience with more than 2,500 km of pipelines in southwest U.S. These pipelines were built with specific attention to design, operation and regulation for CO_2 including safety enhancing technologies and pipeline integrity management. The result has been a strong safety record for a system that has transported CO_2 to hundreds of injection wells, which have been in operation for more than 30 years with few reported incidents.

The Intergovernmental Panel on Climate Change (IPCC), a scientific intergovernmental body set up by the World Meteorological Organization and by the United Nations Environment Programme, has also reviewed CO_2 transportation and storage management. It concluded that the safety of pipeline systems should be similar to those experienced with existing natural gas pipelines, which have few incidents. In addition, the IPCC noted that injection and subsurface safety issues will need to be considered in the design and implementation of storage, monitoring and verification programs.

With more than 540,000 km of energy pipelines in operation in Canada, industry has a strong track record of safety in the production and transportation of petroleum products, natural gas and CO_2. Much of what has been learned to date can be applied directly to the construction and operation of new carbon capture, transportation and storage facilities. The design, operation and regulation of these projects must be carried out in a manner that properly identifies and manages safety considerations in the interests of the public.

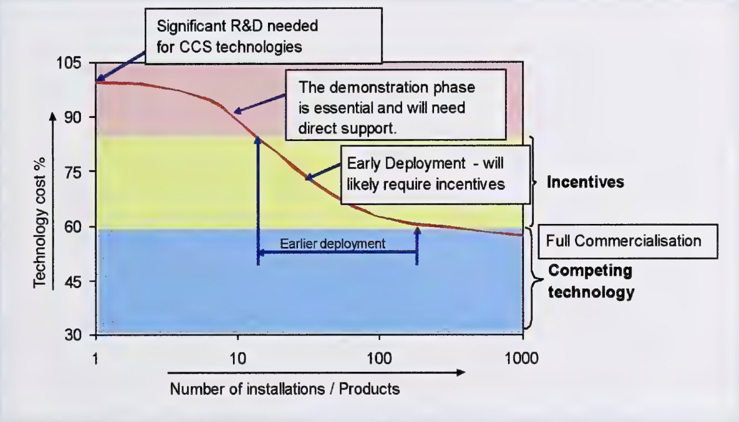
In order to capture and reflect this growing experience, the Council recommends that the Canadian Standards Association (CSA) be approached to update and incorporate standards for CO_2 transportation and storage in the applicable national standards.

6.0 Longer-Term R&D and Technology Needs

6.1 Technology Advancement Model

Carbon capture is not considered a new technology; it consists of a series of processes and equipment installations some of which are not yet of commercial scale and others, such as gas compression, which are well understood. The technical challenge is one of design of an integrated facility that maintains the operating integrity and reduces overall cost of the combined CCS and energy production facility.

CCS - Develop, Demonstrate and Deploy



Source: **Development Council Evaluation**

The development of process technology generally follows a pathway that is well understood as described in the preceding chart. The three stages are Develop; Demonstrate; and Deploy. This cycle typically takes 10 to 15 years to progress through to commercial application and, in this case, we have yet to see the demonstration phase. Capture costs are anticipated to decrease over time as knowledge and experimentation improves the technology used. Significant cost savings (30 to 50 per cent) have been shown for other large novel processes but they occur only after, in some cases, hundreds of installations. An estimate of the potential range of CCS cost savings would require more experience with specific integrated installations. Since some of the technology and processes employed are at a mature development stage, it is anticipated that the reduction in costs would be less than with a fully new process development.

The storage of CO_2 (and, more specifically, the MMV required) employs new technology and process developments or adaptation of technologies already in use in other applications. Storage is expected to benefit from collaborative research, some of which is already under way in Sleipner, Norway, in Salah, Algeria, and in Weyburn, Saskatchewan. The methods to delineate the best storage reservoirs and improvements in MMV will continue to improve in concert with ongoing capture technology developments in 10 to 15 years. As the storage costs are only five to 10 per cent of the overall CCS costs, the potential savings in this area is not significant.

6.2 Research & Development Priorities – Global Effort

For CCS technology to significantly reduce the level of GHG emissions, a long-term global effort will be required. Canadian technology thrusts must be complemented by international cooperation on technology development. Any progress will require significant investments in technology to:

- Reduce the cost of CO_2 separation and capture by some 30 to 75 per cent;
- Reduce significantly the energy required for separation and capture;
- Determine accurately the costs of CO_2 separation and capture at a facility level;
- Support efficient CO_2 transport infrastructure;
- Delineate oil and gas sites, saline formation and other sites for large volume storage;
- Demonstrate a track record of successful CO_2 storage experience; and
- Integrate existing monitoring techniques.

6.3 Portfolio Approach

Investments in CCS research and technology require recognition that there are no silver bullets and that technology investments involve risks. A balanced portfolio must be developed as a hedge against technical risks. To this end, the Government of Alberta, through the Alberta Energy Research Institute (AERI), is investing in storage and monitoring in a large-scale CO_2 EOR environment through funding of the International Energy Agency's GHG Weyburn-Midale CO_2 Monitoring and Storage Project and the Pembina Cardium Project

The project at the EnCana Weyburn Field is the largest CO_2 storage project in the world. Results will be released by the Petroleum Technology Research Centre (Regina) in a Best Practices Manual in 2012. These results will prove invaluable to advancing Alberta's planned EOR CO_2 storage. The recently completed Pembina Cardium Project builds on Weyburn and includes other monitoring technologies.

The focus has to be large-scale potential of the technology with market acceptance and timing for commercial readiness serving as important criteria.

6.4 Capture Technologies

Capture technologies use a variety of methods including post-combustion, pre-combustion and oxyfuel combustion for concentrating the streams of CO_2 from various emitting sources. These bulk streams may include hydrogen, oxygen, nitrogen, hydrogen sulphide, organics and other sulphur and nitrogen contaminants. Pre-combustion separation of streams that are carried out as part of the process have a major advantage over post-combustion process streams, where the only purpose is

to capture the CO_2. In oxyfuel combustion, oxygen is used instead of air for burning fuels, thereby producing a concentrated stream of CO_2.

Current commercial technology uses chemical and physical solvents to separate CO_2. Many companies are working on improved solvents for capture primarily to reduce the energy required to regenerate the solvent. While some advanced CO_2 absorbing solvents are nearing the commercial stage, the chilled ammonia solvent system, for example, is still at a pilot stage and ionic solvents are at a laboratory stage. Separation methods that use membranes, solid sorbents, cryogenic separation or organometallic frameworks are also at an early stage.

6.5 Transport Technologies

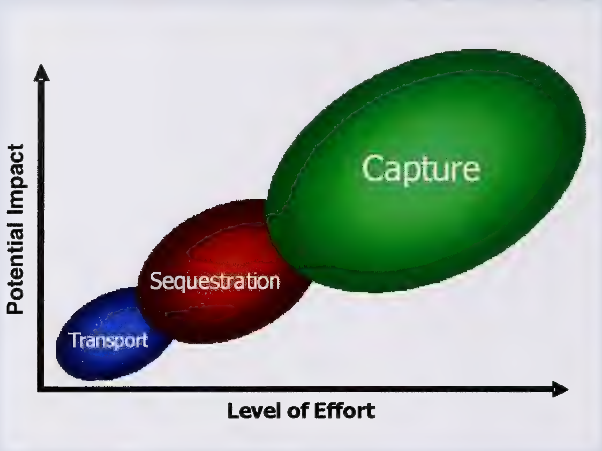
A transportation system is needed to connect capture and compression sites with storage sites. Transport can be done via pipeline or by tanker. For economic reasons the CO_2 is compressed to either a supercritical or liquid phase and CO_2 transport by pipeline is in commercial use today in North America. The technology of CO_2 pipelining is well understood, although there is still potential work in areas like CO_2 purity and issues with dense phase liquids.

6.6 Storage Technologies

CO_2 can be stored in geological media by various means through a variety of physical and chemical trapping mechanisms. In physical traps, CO_2 retains its structure and characteristics, while in chemical traps it is adsorbed onto organic material or it dissolves in formation water, with the subsequent potential of precipitating as a mineral carbonate. The most important storage formations available in western Canada include reservoirs for EOR, depleted gas or oil fields, deep saline formations, and coal seams. R&D work related to storage of CO_2 storage will be in areas such as capacity, downhole flow, and monitoring techniques. Much of this research is already under way – as in the previously mentioned Pembina Cardium and Weyburn-Midale Project, which has a varied research program addressing geophysical and geochemical monitoring, verification, wellbore integrity and risk assessment – and recommendations from that research should help advance new storage projects in Alberta.

The Canada/Alberta ecoENERGY CCS Task Force and the Canadian CCS Technology Roadmap defined a series of research priorities specific to Canada for capture, transport and storage topics. A roundtable review and ranking of these areas was conducted by the Council's Technology & Infrastructure Expert Group. This high level review was carried out to set priorities for the R&D work by contrasting the subjects as to achievability, impact and timing. Results of this review are shown in the following chart.

CCS Technology Research and Development Advancement



Source: **Development Council Evaluation**

For initiatives related to CO_2 capture, almost all the areas of work are medium to high impact, with lower range of achievability and long time frames to resolution.

Transportation of CO_2 is well proven and R&D will only fine-tune existing information. This has a lower risk, with shorter timelines. There is a need for more work on examining CO_2 pipeline safety – both the historical record and the differences from petroleum pipelines. Work with the CSA to develop pipeline standards is also appropriate.

The group is optimistic about achieving answers to the potential research subjects related to storage questions. Relatively short timeframes are required with low to medium impact expected. MMV work will be an area that may have longer timeframes and greater research effort – one where collaboration with international work to avoid duplication is important.

Alberta's experience suggests that, for successful government-industry models[15] to share costs and risks of "game-changing" technologies, $100 to $200 million per annum is needed as a base level for government-industry expenditure on research and adapting technology to Alberta's needs.

[15] Based on AERI experience with the integrated programs in hydrocarbon upgrading and gasification with CCS.

Appendix

The Mandate of the CCS Development Council

The key measure of success for the Council is to provide recommendations that will successfully facilitate the immediate, medium- and long-term implementation of CCS in Alberta.

In support of this measure of success, the Council has been mandated to:

- develop recommended approaches to kick-start large-scale CCS projects as soon as possible;
- develop a coherent mid- and longer-term work plan or blueprint for implementing CCS in Alberta;
- develop a set of appropriate timelines, policy, and regulatory requirements to accelerate implementation;
- examine and propose a suite of tools and incentives to ensure Alberta industry maintains a leadership role in implementing CCS technology; and
- respond to the recommendations of the Canada/Alberta ecoENERGY Carbon Capture and Storage Task Force (following page).

The Council is made up of senior industry, academic, and government representatives that have a proven track record for successful implementation of large-scale projects/innovative technologies, an ability to collaborate, and have specific interests in CCS implementation.

In support of the Council, an Advisory Group of senior government and private sector management was established. The Advisory Group has set up Expert Groups in the areas of the Business Case/Fiscal, Policy & Regulatory and Technology & Infrastructure aspects of CCS.

Response to the Canada/Alberta ecoENERGY Carbon Capture and Storage Task Force Recommendations (2008)

Three Immediate Actions Suggested by the ecoENERGY CCS Task Force

Immediate Action #1 – Federal and provincial governments should allocate $2 billion in new public funding to leverage the billions of dollars of industry investment in the first CCS projects; this funding should be distributed expeditiously through a competitive request for proposals process so that these phase-one projects are operational by 2015.

Council's Response: On July 8th, 2008, the Government of Alberta committed $2 billion to the development of CCS. At the time of writing, the government has put in place a competitive request for proposals process and will award funding under that program in 2009.

Immediate Action #2 – Authorities responsible for oil and gas regulation should provide regulatory clarity to move the first CCS projects forward by: quickly confirming legislation and regulation related to pore-space ownership and disposition rights; clearly articulating the terms for the transfer of long-term liability from industry to government; and increasing the transparency of regulatory processes.

Council's Response: Section 5 of this report includes specific recommendations on a proposed regulatory framework for CCS.

Immediate Action #3 – Federal and provincial governments should ensure as much opportunity for CCS projects under the GHG regulatory frameworks as for any other qualifying emission reduction option. This will require the creation of CCS-specific measurement and crediting protocols.

Council's Response: The Council was not asked by Minister of Energy to address this issue. Alberta's GHG regulatory system enables the recognition of CCS based offset credits (currently a protocol for EOR projects using CO_2), and through its technology fund, opportunities for further support to advancing CCS. Specific recommendations have also been included in this report recognizing the potential to use GHG credits to help bridge the financial gap for implementing CCS such as the use of multiple-credits.

Three Next Steps Suggested by the ecoENERGY CCS Task Force

Next Step #1 – Industry and both government levels should form a collaborative framework including an advisory group over the next two years to coordinate discussion, to institutionalize learning, and to potentially carry out specific aspects of immediate actions 1, 2, and 3. This may evolve into a more formal organization as future needs are assessed.

> **Council's Response:** The Council's mandate directly relates to this recommendation and was the next phase in implementing the Task Force recommendations. This report sets out guiding principles and two options for developing a CCS governance approach in Alberta (see Section 5).

Next Step #2 – Federal and provincial governments should provide stable financial incentives to help drive CCS activities beyond the phase-one projects. These may include the continuation of RFPs for phase-two projects, CO_2 storage incentives, and/or the use of tax and royalty incentives.

> **Council's Response:** The Council has provided detailed recommendations and options to implement this recommendation from the Task Force. The Council's report develops this recommendation further and confirms that a solid business case exists for continued government support for CCS.

Next Step #3 – Canadian-based research organizations and technology developers should focus research and demonstration efforts on CCS to achieve two goals: to drive down the cost of existing CCS technologies; and to enable the deployment of next generation CCS technology and processes – the federal and provincial governments should provide financial support for these activities.

> **Council's Response:** The Council has provided several new recommendations for priority R&D work in this report (see Section 6).

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Bill Andrew, Director and Chief Executive Officer, Penn West Energy
John Brannan, Executive Vice President & President, Integrated Oil Division, EnCana
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Bibliography

The following referenced documents provided guidance to the Council but do not necessarily reflect the views or final conclusions and recommendations of the Council.

Alberta Environment, 2008, *Climate Change Strategy*
http://environment.gov.ab.ca/info/library/7894.pdf

Alberta Energy, 2008, *Launching Alberta's Energy Future – Provincial Energy Strategy*
http://www.energy.alberta.ca/Org/pdfs/AB_ProvincialEnergyStrategy.pdf

Alberta Mines and Minerals Act RSA 2000
http://www.qp.gov.ab.ca/documents/Acts/m17.cfm?frm_isbn=9780779737024

Alberta Water Act RSA 2000
http://www.qp.gov.ab.ca/Documents/acts/W03.CFM

Canadian Energy Research Institute, 2005, *Economic Impacts of Alberta's Oil Sands*
http://www.ceri.ca/Publications/documents/OilSandsReport-Final.PDF

Climate Change Capital, 2008, *Workshop on financial mechanisms for CCS deployment*
(Contact: CCS Development Council Secretariat at 780-644-7512)

Energy Information Administration, 2008, *Country Analysis Brief: Canada*
http://www.eia.doe.gov/emeu/cabs/Canada/pdf.pdf

EPIC Consulting Services Ltd. and Sproule, 2008, *Alberta Enhanced Oil Recovery CO_2 Demand Study*
(Contact: CCS Development Council Secretariat at 780-644-7512)

Ian Murray and Co. Ltd., 2008, *Alberta CO_2 Capture Cost Survey and Supply Curve*
(Contact: CCS Development Council Secretariat at 780-644-7512)

ICO_2N, 2007, Carbon Capture and Storage: A Canadian Environmental Superpower Opportunity
http://www.iCO2n.com/docs/media/ICO2N%20Report_Carbon%20Capture%20and%20Storage_A%20Canadian%20Environmental%20Superpower%20Opportunity.pdf

International Energy Agency (IEA) study, 2008, *Carbon Dioxide Capture and Storage: A Key Carbon Abatement Option*
http://www.iea.org/Textbase/publications/free_new_Desc.asp?PUBS_ID=2052

National Energy Board, 2006, *Canada's Oil Sands, Opportunities and Challenges to 2015: An Update*
http://www.nrtee-trnee.com/eng/publications/getting-to-2050/Getting-to-2050-low-res.pdf

National Round Table on the Economy and the Environment, 2007, *Getting to 2050: Canada's Transition to a Low-emission Future*
http://www.nrtee-trnee.com/eng/publications/getting-to-2050/Getting-to-2050-low-res.pdf

RPS Energy, 2008, *Alberta Gas Pool Carbon Storage Estimate*
(Contact: CCS Development Council Secretariat at 780-644-7512)

The ecoENERGY Carbon Capture and Storage Task Force Report, 2008, *Canada's Fossil Energy Future*
http://www.energy.alberta.ca/Org/pdfs/Fossil_energy_e.pdf

University of Alberta, School of Business, Centre for Applied Business Research in Energy and the Environment, 2008, *Carbon Capture and Storage Policy Options for Alberta*
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Governance should include a cooperative public and private sector collaboration to actively manage and accelerate the development of the capture, transportation, EOR, and direct storage components of a CCS system.